UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: ANALYSIS OF REFRIGERATION SYSTEM WORKING WITH NANOLUBRICANT

SESI PENGAJIAN: 2011/2012

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ANALYSIS OF REFRIGERATION SYSTEM WORKING WITH NANOLUBRICANT

MOHD HAZWAN SYAFIQ BIN HARUN

A thesis submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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JUNE 2012

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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STUDENT'S DECLARATION

I declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for the award of the degree of Bachelor of Mechanical Engineering.

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DEDICATION

In the name of Allah, the Most Beneficent, the Most Merciful

Special dedication to my family members especially to my mother Puan Maznah Binti Ali who always give me encouragement in my life, my study and to finish my undergraduate project.

To my supervisor
Encik Mohd Yusof Bin Taib.

To my academic advisor
Encik Lee Giok chui.

To all FKM's staff and lecturers
To all my classmates and all my friends out there
Thank you for your supporting and teaching

Thank you for everything that you gave during my studies and the knowledge that we shared
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ABSTRACT

Nanofluid is suspended of nanoparticles in a base fluid like water and lubricant oil with the purpose to increase rate of hate transfer either convection or conduction. It has been used in wide application such as in heat exchanger, automotive cooling and refrigeration system. The application of nanofluid in refrigeration system is a new approach with the purpose to increase rate of hate absorbed by evaporator. By increasing rate of heat absorbed in evaporator, the refrigeration system is able to cool down the refrigeration space faster than normal system. Currently, there are two types of approaches of nanofluid application in refrigeration system: 1) mixing with refrigerant and 2) mixing with refrigerant lubricant. Both of these approaches have no chose agreement each other and future research still in progress in this field. In order to find agreement between other researchers, this project has been conducted based on nanolubricant-refrigerant (called ‘nanolubricant’) approach. In this project Alumina and Carbon Nanotubes nanoparticles have been used in experiment. This two types of nanoparticles are selected based on study conducted by previous researchers who showed encouraging results. The nanolubricant is prepared by using 'two steps' technique which is alumina and CNT particles diluted with 'poly-ester lubricant' with concentration of 0.2%. There are three types of experiment have been conducted in this project. The first experiment is using normal lubricant which is ‘poly-ester’ lubricant, followed by experiments using CNT lubricant' and 'Alumina lubricant. The result shows that, with addition of nano particle into 'poly-ester lubricant' it increases the rate of refrigeration system performance. The maximum rate of performance improvement by adopting CNT into lubricant is 8.29%, while by using Alumina lubricant the maximum rate of performance improvement is 13.8%. As a calculation, Alumina is more suitable compared to CNT to be mixed with Ploy-ester lubricant for refrigeration system.

ABSTRAK

Nanofluid adalah pada campuran nanopartikel di dalam cecair asas seperti air dan minyak pelincir dengan tujuan untuk meningkatkan kadar pemindahan haba sama ada melalui cara perolakan atau konduksi. Ia telah digunakan dalam aplikasi yang meluas seperti dalam penyejukan penukar haba, automotif dan sistem penyejukan. Aplikasi nanofluid dalam sistem penyejukan adalah satu pendekatan baru dengan bertujuan untuk meningkatkan kadar haba diserap oleh penyejat. Dengan meningkatkan kadar penyerapan haba pada penyejat, sistem penyejukan mampu untuk menyejukkan ruang penyejukan lebih cepat daripada sistem biasa. Pada masa ini, terdapat dua pendekatan aplikasi nanofluid dalam sistem penyejukan: 1) dicampur dengan bahan penyejuk dan 2) dicampur dengan pelincir penyejuk. Kedua-dua pendekatan ini tidak terikat dengan setiap penyelidikan yang lain dan masa depan kajian ini masih jauh boleh dimajukan dalam bidang ini. Bagi mendapatkan persamaan antara penyelidik lain, projek ini telah dijalankan berdasarkan pendekatan nanolubricant-penyejukan (dipanggil 'nanolubricant'). Dalam projek ini nanopartikel Alumina dan Carbon Nanotube telah digunakan dalam eksperimen, dua jenis nanopartikel dipilih berdasarkan kajian yang dijalankan oleh penyelidik terdahulu yang menunjukkan hasil yang menggalakkan. Nanolubricant sediakan dengan menggunakan teknik 'dua langkah' iaitu Alumina dan CNT dicairkan dengan' pelincir poli-ester ' dengan kepekatan 0.2%. Oleh itu, tiga jenis eksperimen telah dijalankan dalam projek ini. Eksperimen ini menggunakan minyak pelincir biasa iaitu 'poli-ester', diikuti oleh eksperimen yang menggunakan minyak pelincir ‘CNT’ dan pelincir Alumina. Hasil menunjukkan bahawa, dengan penambahan nanopartikel, ia menjadikan 'minyak pelincir poli-ester' meningkatkan kadar prestasi sistem penyejukan. Kadar maksimum peningkatan prestasi dengan menambahkan CNT ke pelincir adalah 8,29%, manakala dengan menggunakan pelincir Alumina kadar maksimum peningkatan prestasi adalah 13.8%. Melalui pergiraan, Alumina adalah lebih sesuai berbanding CNT untuk dicampurkan dengan pelincir ‘Poli-ester’ untuk sistem penyejukan.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Nanofluids are a relatively new class of fluids which consist of a base fluid with nano-sized particles (1–100 nm) suspended within them. These particles, generally a metal or metal oxide, increase conduction and convection coefficients, allowing for more heat transfer in wide application such as in heat exchanger, automotive cooling and refrigeration system. Figure 1 provides an example of nanometer size of particles in comparison with millimetre and micrometer in order to understand the concept of nanoparticles clearly.

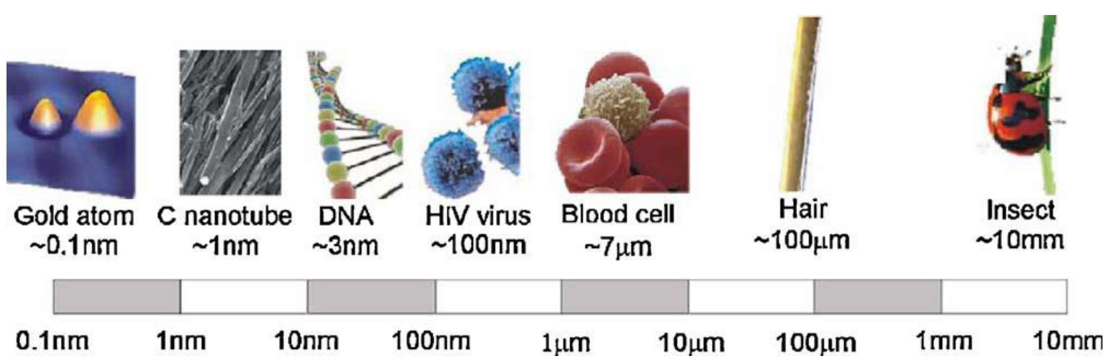


Figure 1: Length scale of nanofluids.

Source: Serrano E (2009)

In the past few decades, rapid advances in nanotechnology have lead to emerging of new generation of coolants called "nanofluids". Nanofluids are defined as suspension of nanoparticles in a basefluid. Some typical nanofluids are ethylene glycol based copper nanofluids and water based copper oxide nanofluids, Nanofluids are dilute suspensions of functionalized nanoparticles composite materials developed about a decade ago with the specific aim of increasing the thermal conductivity of heat transfer fluids, which have now evolved into a promising nanotechnological area. Such thermal nanofluids for heat transfer applications represent a class of its own difference from conventional colloids for other applications. Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids possess the following advantages:

- High specific surface area and therefore more heat transfer surface between particles and fluids.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

The nanofluid is a new type of heat transfer fluid by suspending nano-scale materials in a conventional host fluid and has higher thermal conductivity than the conventional host fluid. Recently scientists used nanoparticles in refrigerations systems because of its remarkable improvement in thermo-physical, and heat transfer capabilities to enhance the efficiency and reliability of refrigeration and air conditioning system. The nanorefrigerant is one kind of nanofluid and its host fluid is a refrigerant. A nanorefrigerant has a higher heat transfer coefficient than the host refrigerant and it can be used to improve the performance of refrigeration systems. The heat transfer coefficient of a fluid with higher thermal conductivity is larger than that of a fluid with lower thermal conductivity if the nusselt numbers of them are the same. Therefore, researches on improving thermal conductivities of nanorefrigerants are necessary.

1.2 NANOFLUIDS APPLICATION

Heat transfer fluids are the most important part for cooling applications in many industries including transport, energy, manufacturing and electronics. Nanofluids can be used to improve heat transfer and energy efficiency a variety of thermal system, including the important applications of refrigeration vehicles. Some applications of nanofluids will discuss the next sub chapter.

1.2.1 Nanofluid for Lubrication Applications

Solid lubricants useful in situations where conventional lubrication is not enough liquid, such as high temperature and excessive contact pressure. Their lubricating properties are due to the layer structure at the molecular level with weak bonding between the layers. Graphite and molybdenum disulphide (MoS2) is the main material used as solid lubricants. Other useful solid lubricants include boron nitride, tungsten disulfide, polytetrafluorethylene (PTFE), etc. to improve the tribological properties of lubricating oils, solid lubricant nanoparticles to disperse. Recent studies have shown that the lubricating oil with additional nanoparticles exhibit improved load carrying capacity, anti-wear and frictionreduction property. Xu, et.al. (1996) investigate the tribological properties of lubricating oil and paraffin oil twophase diamond nanoparticles, and the results showed that, under boundary lubrication conditions, the type of two-phase lubricant has excellent load-carrying capacity, anti-wear and friction reduction properties (Azrul, 2010).

1.2.2 Nanofluid for Biomedicine Applications

Nanofluids have many applications in the biomedical industry. For example, nanofluids are used to producing effective cooling around the surgical region and thereby enhancing the patient's chance of survival and reducing the risk of organ damage. In a contrasting application to cooling, nanofluids could be used to produce a higher temperature around tumors to kill cancerous cells without affecting nearby healthy cells (Jordan, et al., 1999).

1.2.3 Nanofluid for Cooling Applications

Developments in new technologies such as highly integrated microelectronic devices, the engine power output is higher, and the reduction of cutting fluids used continuously increasing heat load, which requires the development of cooling capacity. Thus, there is need for a new heat transfer fluids and innovative ways to achieve better cooling performance. In general, the conventional heat transfer fluid has the characteristics of poor heat transfer compared to the solid, most solids have thermal conductivities orders of magnitude greater than that of conventional heat transfer fluids. Therefore, the liquid containing suspended solid particles are expected to exhibit a significant increase in thermal conductivity compared with conventional heat transfer fluids. In addition, normal coolant operating temperature can be increased since nanofluids have obtained a higher boiling point, which is desirable for maintaining single phase coolant flow. The results of nanofluids research are being applied to the cooling of automatic transmission with variable operating speeds conducted by Tzeng, et al. (2005) found the CuO nanofluids produced the lowest transmission temperatures both at high and low rotating speeds (Azrul, 2010).

1.2.4 Others Application

There are unending situations where an increase in the heat transfer effectiveness can be beneficial to be the quality, quantity, and cost of product or process. In many of these situations, nanofluids are good candidates for accomplishing the enhancement in heat transfer performance. For example, nanofluids have potential application in buildings where increases in energy efficiency could be realized without increases in energy efficiency without increased pumping power. Such an application would save energy in as heating, ventilating and air conditioning system while providing environmental benefits. In the renewable energy industry, nanofluids could be employed to enhanced heat transfer from solar collectors to storage tanks and increase the energy density. Nanofluid coolants also have potential application in major process industries, such as materials, chemical, food and drink, oil and gas, paper and printing, and textiles (Azrul, 2010).

1.3 PROBLEM STATEMENTS

Previous research on nanoparticles for refrigeration system has been conducted in order to increase heat absorption in evaporator so that more heat will be absorbed. In current practice, there are two types of nanoparticles preparation:

(i) Mix refrigerant with nanoparticles

(ii) Mix refrigerant lubricant with nanoparticles.

Previous research is more to domestic refrigerator as case study and type of nanoparticle were focused on selected working with selected refrigerant. Until now there is no work or research on mini bar refrigerator working with nanoparticles.

1.4 OBJECTIVES

The objectives of this project are:

i) Preparation nanolubricant for refrigeration application
ii) To analyze performance of mini bar refrigerator by introducing different of nanoparticles into the system.

1.5 SCOPES

As guideline to author in order to ensure that the project is success, several scopes have been outlined as described below:

i) Fundamental study of nanofluid particles and refrigeration system.
ii) Experiment of mini bar refrigerator working without nanoparticle (base data).
iii) Preparation of nanolubricant for refrigerant.
iv) Conduct experimental of refrigeration system with normal lubricant.
v) Carry out performance analysis for refrigeration system with nanolubricant

1.6 THESIS ORGANIZATION

The thesis is organized in five chapters. Chapter 1 presents a general background of the research focus, problem statement, and research objectives and scopes.

Chapter 2 covers the literature review. First, an introduction to highlight the point that will be discussed in this chapter. Practical application in refrigeration system, advantages and disadvantages of using nanofluid and benefit of nanofluid in refrigeration system is presented.

In chapter 3, the research methodology is presented. The development phases are presented. The phases are including analysis about the system; designing of system needed, flow process of the system, list the entire requirement needed and also testing the system. This chapter also intended to provide sufficient details on the method used, procedures followed, and overall development process.

In Chapter 4, all the results and discussions are presented based on the experimental results. Finally, conclusion and contribution of the thesis are presented in

Chapter 5, along with the suggestion for future works based on the analysis and evaluation proposed method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This section we will discuss about the fundamental of refrigeration system and all parameter that should be consider in this study. Besides that, this chapter will analyze and overview the application of nanofluid in refrigeration system, advantages and disadvantages of using nanofluid in refrigeration system and some research related to this title of the study.

2.2 REFRIGERATION SYSTEM

A refrigeration system is a combination of components and equipment connected in a sequential order to produce the refrigeration effect. (Shan K.Wang, 2000). In real applications, vapor-compression refrigeration system are the most commonly used in refrigeration system.

Refrigeration deals with the transfer of heat from a low temperature level at the heat source to a high temperature level at the heat sink by using a low boiling refrigerant.

2.2.1 Vapour compression cycle

Normally heat flows naturally from a hot to a colder body but in refrigeration system the opposite must occur like heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant, which absorbs heat and hence boils or evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat that it has gained to ambient air or water and turns back (condenses) into a liquid. In this way heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source. The vapor compressor refrigeration system nowadays is used for all purpose refrigeration. In a basic vapor compression refrigeration cycle, four major thermal processes take place as follows:

i) compression,
ii) condensation,
iii) Expansion,
iv) Evaporation.

Figure 2.1 shows schematic and *P-h* diagram of vapor compression refrigeration system.

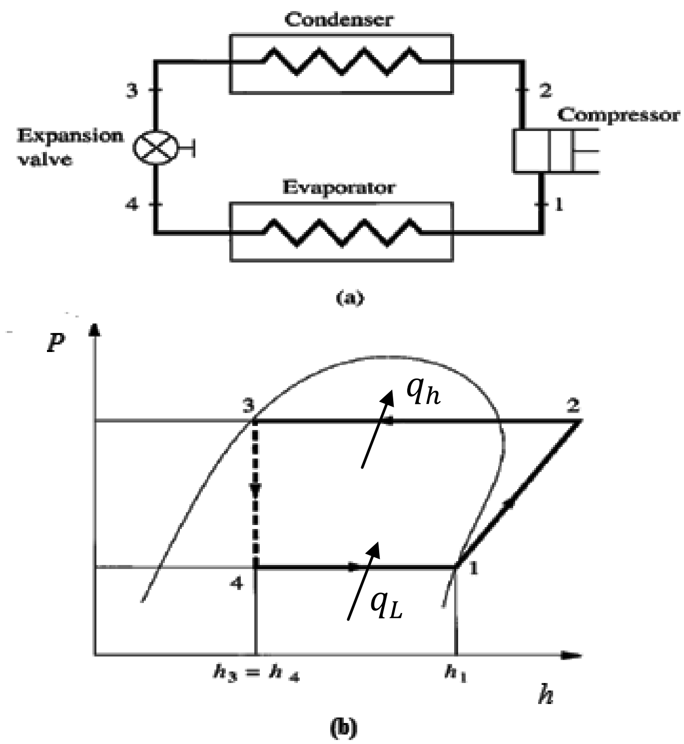


Figure 2.1: (a) Schematics and (b) *P-h* diagram of vapor compression system.
Source: Shan K.Wang (2002)

There are four points in the figure and each point represents the point of interest for analyzing performance parameter and these points can be defined as:

Point 1: Saturated vapor refrigerant phase before entering compressor
Point 2: Superheated refrigerant phase after compressor
Point 3: Saturated liquid before phase entering expansion valve
Point 4: Mixture refrigerant phase after entering expansion valve

Combination of two sequential points produces one process in the system. As shown by Figure 2.1. There are four combinations of sequential points in the system as described below:

1. Point (1-2): This process is a reversible adiabatic compression. From the evaporator, low-pressure saturated refrigerant vapor comes to the

compressor and is compressed into the condenser by volume reduction and increased pressure and temperature.

2. Point (2-3): Process at point 2-3 is reversible heat rejection at constant pressure. From the compressor, high-pressure refrigerant vapor enters the condenser and is liquefied by rejecting the heat to water or air.
3. Point (3-4): This is irreversible expansion at constant enthalpy. From the condenser, high-pressure saturated refrigerant liquid passes through an expansion valve and its pressure and temperature are reduced.
4. Point (4-1): This is reversible heat addition at constant pressure. From the expansion valve, low pressure refrigerant liquid arrives in the evaporator. It boils and in the process absorbs heat from the substance, thereby providing a cooling effect.

From the discussion, the four major thermal take place in vapor compression refrigeration system which is evaporation, compression, condensation and expansion. So, it is important to us to know in detail of these four processes in order to get better understanding in refrigeration system.

2.2.2 Evaporation

Unlike freezing and melting, evaporation and condensation occur at almost any temperature and pressure combination. Evaporation is the gaseous escape of molecules from the surface of a liquid and is accomplished by the absorption of a considerable quantity of heat without any change in temperature. Liquids, means refrigerants evaporate at all temperature with increased rates of evaporation occurring at higher temperatures. The evaporated gases exert a pressure called vapor pressure. As the temperature of the liquid rises, there is a greater loss of the liquid from the surface, which increases the vapor pressure. In the evaporator of a refrigeration system, a low-pressure cool refrigerant vapor is brought into contact with the medium or matter to be cooled, absorbs heat, and hence boils, producing a low-pressure saturated vapor.

No work is done during evaporation, the change of kinetic energy between points 4 and 1 is small and it is usually ignored (quasi equilibrium).

$$h_4 + q_L = h_1 + 0 \quad (2.1)$$

$$q_{in}, \; = \mathrm{h}_1 - \mathrm{h}_4 \quad (2.2)$$

Where q_L, is defined as the refrigerating effect q_{in}, (J/kg), is :

2.2.3 Compression

Using shaft work of a compressor raises the pressure of the refrigerant vapor obtained from the evaporator. The addition of heat may play a role in raising the pressure. Increasing the gas pressure raises the boiling and condensing temperature of the refrigerant. When the gaseous refrigerant is sufficiently compressed, its boiling point temperature is higher than the sink's temperature.

For isentropic compression between points 1 and 2, the steady flow energy equation and can be applied by ignoring the change of kinetic energy, therefore energy equation can be written as;

$$\mathrm{h}_1 - 0 = \mathrm{h}_2 + w \quad (2.3)$$

$$-w = \mathrm{h}_2 - \mathrm{h}_1 \quad (2.4)$$

$-w$ is the work input to the compressor and can be written as w_{in}, (kJ / kg). Therefore Equation (2.4) can be written as:

$$\mathrm{W}_{in} = \mathrm{h}_2 - \mathrm{h}_1 \quad (2.5)$$

2.2.4 Condensation

This is a process of changing a vapor into a liquid by extracting heat. The high-pressure gaseous refrigerant, which carries the heat energy absorbed in the evaporator and the work energy from the compressor, is brought into the condenser. The condensing temperature of the refrigerant is higher than that of the heat sink and therefore heat transfer condenses the high pressure refrigerant vapor to the high-pressure saturated liquid. The heat source has been cooled by pumping heat to the heat sink. Instead of using a condenser to reject heat, the refrigerant vapor can be discharged to the atmosphere, but the technique is impractical. Condensing the refrigerant gas allows reuse at the beginning of the next cycle. In some practical applications, it is desired that the condenser cools the refrigerant further, below the condensation temperature. This is called subcooling, which is usually observed in the condenser to reduce flashing when the refrigerant pressure is reduced in the throttling device. This method provides a reduction in the amount of gas entering the evaporator and hence an improvement in the system performance (Dincer, 1997).

For condensation between points 2 and 3, energy equation can be written as;

$$h_2 + q_H = h_3 - 0 \tag{2.6}$$

By rearranging the equation (2.6), yields ;

$$-q_H = h_2 - h_3 \tag{2.7}$$

Where $-q_H$ is defined as heat rejected by the refrigerant in the conductor, q_H $(^{kj}/_{kg})$

2.2.5 Expansion

The condensed refrigerant liquid is returned to the beginning of the next cycle. A throttling device such as valve for the expansion process is used to reduce the pressure of the refrigerant liquid to the low-pressure level and the boiling temperature of the refrigerant to below the temperature of the heat source. Energy losses through this pressure reduction must be offset by additional energy input at the pressurization stage.

For the throttling process between points 3 and 4, assuming that the heat loss is negligible, the energy equation can be written as,

$$h_3 + 0 = h_4 + 0$$

Therefore,

$$h_3 = h_4 \tag{2.8}$$

2.2.6 Coeffficient of performance (COP)

The coefficient of performance is a measure of efficiency of the refrigeration system and is defined as ratio heat removed by the evaporator to the net work done by the compressor.

$$cop = \frac{h1 - h4}{h2 - h1} \tag{2.9}$$

2.3 HISTORY OF NANOFLUID

Process to produce an advance liquid was undertaken in early 1981 when DB.Tuckerman introduced microchannel technologies. Four years later, Argonne National Laboratory began a program to develop advanced liquid. Various initiatives have been made from micro to nano-sized particles after Choi aware Argonne abilitily to nanoparticles production. Choi in 1995 has developed the concept of showing the nanofluid large expansion of the heat is transported in suspension of copper or aluminum nanoparticles in water and other common liquids. For decades, research institutions around the world have set up a research group of the nanofluid and in no time, nanofluids become a new field of scientific research has grown rapidly in last few years. Despite recent advances, such as the discovery of unexpected thermal property, the proposed new mechanism, and proposed non-conventional model, the mysteries nanofluids mystery solved. Nanofluids are inter-disciplinary ensemble several fields of science and technology. Much work is necessary in every field nanofluids, from basic to the formation of large-scale production. Table 2.1 summarized the history of the emergence of nanofluid as a new field of inquiry.

Table 2.1: Timeline of emergence of nanofluids.

Source: Azrul Azam (2010)

Years	Descriptions
1981	D.B. Tuckerman introduces microchannel technology
1985	Argonne National Laboratory start program to develop advance fluids
1991	Choi develops a microchannel heat exchanger for Advance Photon Source at Argonne.
1992	Funding cut for Argonne advance fluids program. Choi turn attention from micro to nano.
1993	Choi learn of Argonne capability for nanoparticle production
1995	Choi presents a seminar paper of the concept of nanofluids at ASME Winter Annual Meeating, San Francisco, CA, Nov. 12-17
1999	Choi’s group publishes the firs SCI article on nanofluid
2001	Choi’s group publishes two papers in Applied Physics Letters
2007	The first single-theme conference on nanofluids was held. The first book on nanofluids, *Nanofluids: Science and Technology*, is published by Wiley

2.4 APPLICATION OF NANOFLUID IN REFRIGERATION SYSTEM

1,1,1,2-Tetrafluoroethane (HFC134a) is the most widely used alternative refrigerant in refrigeration equipment such as domestic refrigerators and automobile air-conditioners. Though the greenhouse warming potential (GWP) of HFC134a is relatively high, HFC134a has been accepted as a long-term alternative refrigerant in many countries. Due to the strong chemical polarity of HFC134a, traditional mineral oil cannot be used in refrigeration systems with HFC134a as the working fluid, thus Polyol-ester (POE) oil is used as the lubricant. However, POE oil is known to be hydroscopic and hydrolytic, so there are many problems in refrigeration systems using POE oil such as wadding deposition, bulging equipment that chokes the flow and severe friction in the compressor. Nanoparticles can be used to improve the working fluid properties due to their special properties. Nano-refrigerant was proposed on the basis of the concept of the nanofluids, which is prepared by mixing the nanoparticles and traditional refrigerant. Table 2.2 show research that had been conduct form others research from year 2007 until 2012.

Table 2.2: Research that had been conducted by others researchers.

Source: Yusof Taib (2011)

Year	Author/s	Nanoparticles	Size of nanoparticles	Refrigerant type	% of concentration	performance
2007	Park and Jung	Carbon Nanotube TiO_2	20 nm OD and 1 μm Length,	R123 and R134a	1% by volume	Enhance heat transfer coefficient up to 36.6%.
2009	Jiang et al	CNT	15 and 80 nm diameter, 1.5 and 10 nm length	R113	0.2, 0.4, 0.6, 0.8 and 1% by volume	At volume fraction is 1.0%, the measured thermal conductivities of four kinds of CNT/R113 nanorefrigerants increase 82%, 104%, 43% and 50%, respectively.
2009	Trisaksri and Wongwises	TiO2	Average 21 nm	R141b	0.01, 0.03 and 0.05% by Volume	Nucleate pool boiling heat transfer deteriorated with increasing particle concentrations.
2009	Peng et al.	CuO	-	R113	0 – 0.5% by weight	Maximum enhancement of heat transfer coefficient is 29.7% is obtained.
2010	Peng et al.	Diamond	10 nm	R113	0 – 5% by weight	The nucleate pool boiling heat transfer coefficient of R113/oil mixture with diamond nanoparticles is increase by 63.4%.
2010	Lee et al.	Al_2O_3/CNT	< 100 nm	NH_3/H_2O	0.06/0.08 % by volume	Heat transfer rate up to 29% higher than those without nanoparticles.
2011	Kedzierski	Al_2O_3	10 nm	R134a	0.5, 1 and 2% by weight	The average heat flux improvement for heat fluxes less than 40kW/m^2 was approximately 105%, 49%, and 155% for the 0.5%, the 1%, and the 2% mass fractions, respectively.

There are many literature reviews which highlighting advantages and disadvantages of nanofluid in refrigeration system and table 2.3 below conclude all of it.

Table 2.3 Advantage and Disadvantage of nanofluid in refrigeration system in existing studied.

Advantage	Disadvantage
1. Nanoparticles can enhance the solubility between the lubricant and refrigerant. Wang and Xie, 2003 found that Tio2 nanoparticles could be used as additives to enhance the solubility between mineral oil and hydrofluorocarbon(HFC) refrigeration. The refrigeration systems using the mixture of R134a and mineral oil appended with nanoparticles Tio2, appeared to give better performance compared to the system using polyol-ester (POE) and R134a. 2. Thermal conductivity and heat transfer characteristics of the refrigerants will be increased. Park and Jung, 2007 investigated the effect of carbon nanotubes (CNT) on nucleate boiling heat transfer of halocarbon refrigerant R134a, results showed that CNTs increase nucleate boiling heat transfer	1. Viscosity not fixed. The viscosity of nanoparticle-water suspensions increases in accordance with increasing particle concentration in the suspension. Therefore, the particle mass fraction cannot be increased unlimitedly. Vassallo, 2001 reported that the viscosity increased so rapidly with increasing particle loading that volume percentages of CNTs are limited to less than 0.2 % in practical systems. 2. Lower specific heat. It found that specific heat of nanofluids is lower than basefluid. Praveen, 2009 reported that cuO/ethylene glycol nanofluids, sio2/ethylene glycol nanofluids and Al203/ethylene glycol nanofluids exhibit lower specific heat compared to basefluids. An ideal refrigerant should possess higher value of specific heat which enables the

coefficient for this refrigerant. 3. Nanoparticles dispersed in lubricant should decrease the friction coefficient and wear rate. Lee, 2009 investigated the friction coefficient of the mineral oil mixed with o.1 vol.% fullerene nanoparticles, results indicated that the friction coefficient decreased by 90% in comparison with raw lubricant. 4. Less energy consumption. Bi ss, 2008 reported that refrigerator's performance was better with 26.1% less energy consumption with 0.1 % mass fraction of Tio2 nanoparticles compared to the HFC134a and POE oil system.	refrigerant to remove more heat. 3. Cannot stand for long term stability of nanoparticles dispersion. Stability of nanofluids has good corresponding relationship with the enhancement of thermal conductivity where the better the dispersion behavior, the higher the thermal conductivity of nanofluids. However the dispersion behavior of the nanoparticles could be influenced by period of time, as the result it will affect the thermal conductivity of nanofluids. Eastman, 2001 reported, thermal conductivity of ethylene glycol based nanofluids containing 0.3 % copper nanoparticles is deceased with time. 4. High cost of nanofluids. Higher production cost of nanofluids is among the reasons that may hinder the application of nanofluids in industry. Methods used to produce nanofluids are required advanced and sophisticated equipments. Lee, 2007 stressed that high cost of nanofluids is among the drawback of nanofluids applications.

2.5 NANOFLUID PREPARATION

Materials for base fluids and nanoparticles are diverse. Stable and highly conductive nanofluids are produced by one and two-step production methods. Both approaches to creating nanoparticle suspensions suffer from agglomeration of nanoparticles, which is a key issue in all technology involving nanopowders. Therefore, synthesis and suspension of nearly non-agglomerated or monodispersed nanoparticles in liquids is significant enhancement in the thermal properties of nanofluids.

2.5.1 Materials for Nanoparticles and Fluids

Modern nanotechnology has enabled the production of metallic or non-metallic nanoparticles with average crystallite sizes below 100 nm. The mechanical, optical, electrical, magnetic, and thermal properties of nanoparticles are superior to those of conventional bulk materials with coarse grain structures. Consequently, research and development investigation of nano phase materials has drawn considerable attention from both material scientists and engineers (Duncan and Rouvray, 1989). Nanoparticles used in nanofluids have been made of various materials, such as oxide ceramics (Al_2O_3, CuO), nitride ceramics (A_lN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO_2, SiC), carbon nanotubes, and composite materials such as alloyed nanoparticles $Al_{70}Cu_{30}$ or nanoparticle core polymer shell composites. In addition to nonmetallic, metallic, and other materials for nanoparticles, completely new materials and structures, such as materials "doped" with molecules in their solid liquid interface structure, may also have desirable characteristics. The common liquid normally used as a base fluid in nanofluid such as water, mineral oil and ethylene glycol.

2.5.2 Method of Nanoparticles Manufacture

The current processes for making metal nanoparticles is Inert Gas Condensation (IGC), mechanical milling, chemical precipitation, thermal spray, and spray pyrolysis. Most recently, Chopkar et al., (2006) produced alloyed nanoparticles Al70Cu30 using ball milling. In ball milling, balls impart a lot of energy to slurry of powder, and in most cases some chemicals are used to cause physical and chemical changes. These nano sized materials are most commonly produced in the form of powders. In powder form, nanoparticles are dispersed in aqueous or organic host liquids for specific applications.

2.5.3 Dispersion Nanoparticles in Liquids

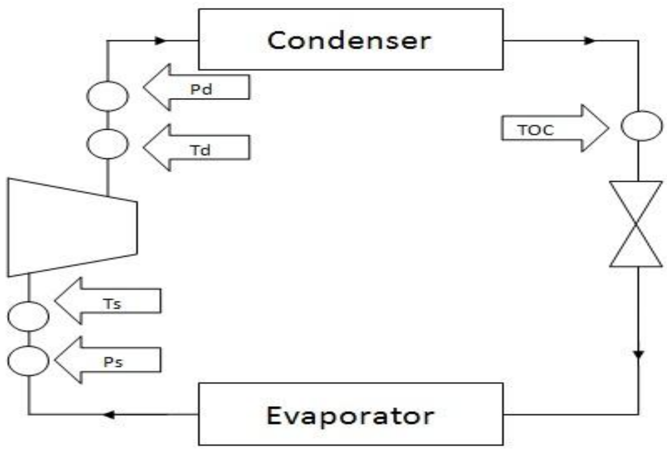
Nanofluids have been produced by two techniques which is single step and two step techniques. The single step techniques is simultaneously makes and disperses the nanoparticles directly into the base fluid and two step techniques starts with nanoparticles produced by one of the physical or chemical systhesis techniques and proceeds to disperse them into a base fluid. Most of the nanofluids containing oxide nanoparticles and carbon nanotubes are produces by the two step process. Moreover, an ultrasonic vibrator or magnetic stirrer was used to sonicate the solution continuously for approximately tenth hours in order to break down agglomeration of the nanoparticles.

2.6 CONCLUSION OF NANOFLUIDS

Nanofluids have a bright future for use as an effective heat transfer fluid and have the potential of more to increase heat transfer and are ideal for applications in heat transfer process. This is an opportunity for engineers to develop simple and compact heat transfer equipment such as heat exchanger. Several published articles show that nanofluids heat transfer coefficient is higher than the liquid common base and provide little or no drop penalty pressure. Therefore further research on nanofluids convective heat transfer and work of a more theoretical research and experiments are needed to understand the clearly and accurately predict the trend of increasing heat transfer.

2.7 TEMPERATURE AND PRESSURE MEASUREMENT LOCATED

Based on previous research which is Performance Optimization of Domestic Refrigerator Using Experimental Method, three temperatures will place outside the tubing which is located at the suction compressor, discharge compressor and the outlet condenser. The pressure we will measure at two points which is at suction pressure which is low pressure side and the discharge of compressor which is high pressure side. So from this the assumption will made that pressure inlet expansion valve is equal to discharge compressor and the pressure outlet expansion valve equal to the pressure suction compressor.



- Pd = Pressure Discharge
- Td=Temperature Discharge
- Ts=Temperature Suction
- Ps= Pressure Suction
- Toc=Temperature Outlet Condenser

Figure 2.2: Location measuring device.

CHAPTER 3

METHODOLOGY

3.1 EXPERIMENT SETUP

This chapter will describe about the experiment setup and also method of the data collection from the experiment using both refrigerant R-134a-poli ester lubricant and refrigerant R-134a-nano poli ester lubricant. This chapter also discuss about method to prepare the nanoparticles with refrigerant lubricant R-134a.

The temperature, pressure point location and the procedure such as evacuation process and charging process (for both refrigerants) also will explain in this chapter. Method analyzing the data from the experimental result also showed in this chapter by using calculation for refrigeration coefficient of performance.

Figure 3.1 shows the project flow chart which started with literature review regarding to refrigeration system and nanoparticle application in refrigeration system.

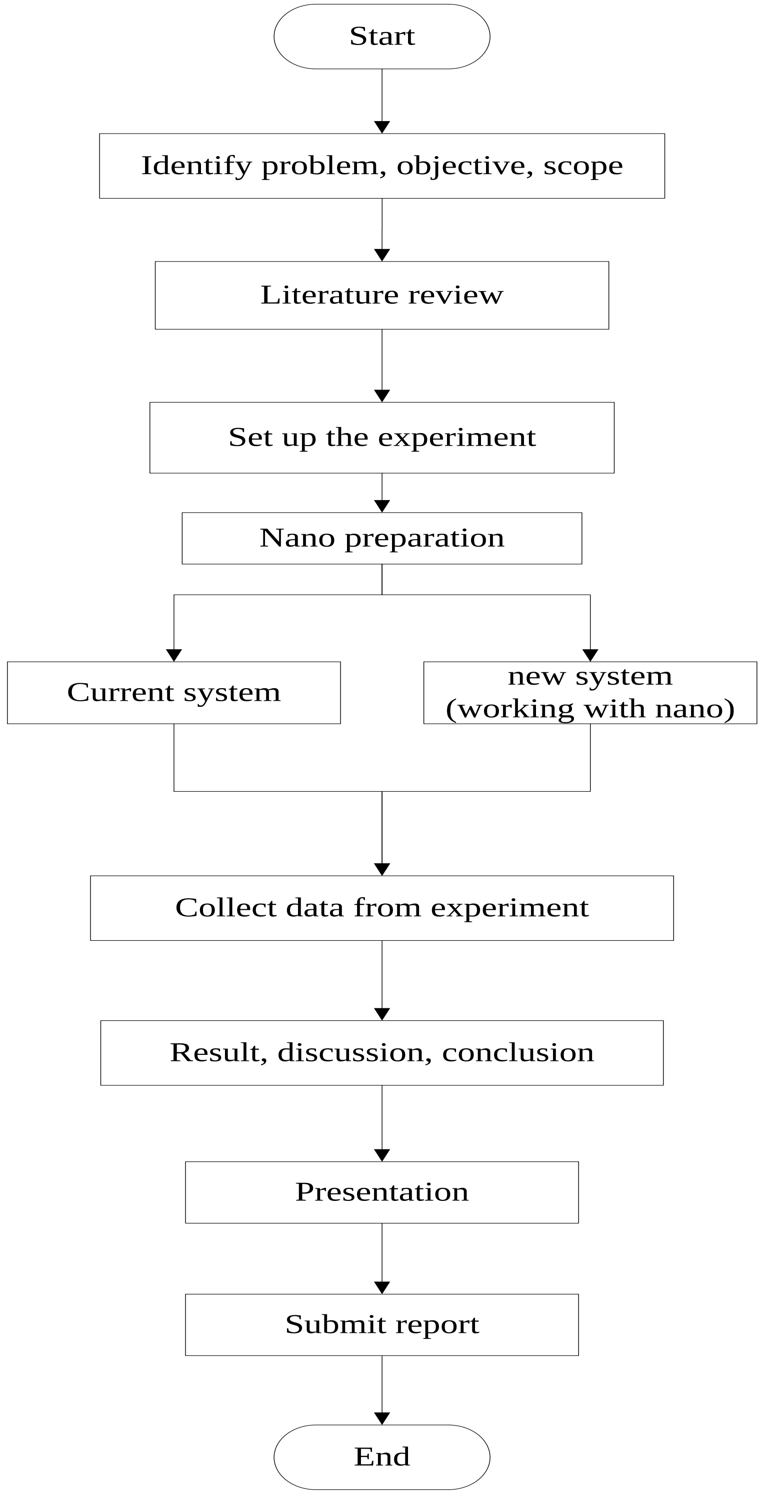


Figure 3.1: Project flow chart.

Two types of experiment will be conducted throughout the study which is experiment on refrigerant system with lubricant R-134a-polieser and another experiment is refrigeration system working with R134a-nano polyester lubricant. Performance of the refrigeration system working with these two lubricants will be analyzed and finally comparison will be done.

Besides the project flow chart, the experimental flow chart also important to make the work successfully conducted. Figure 3.2 shows detailed experimental flow chart in this study.

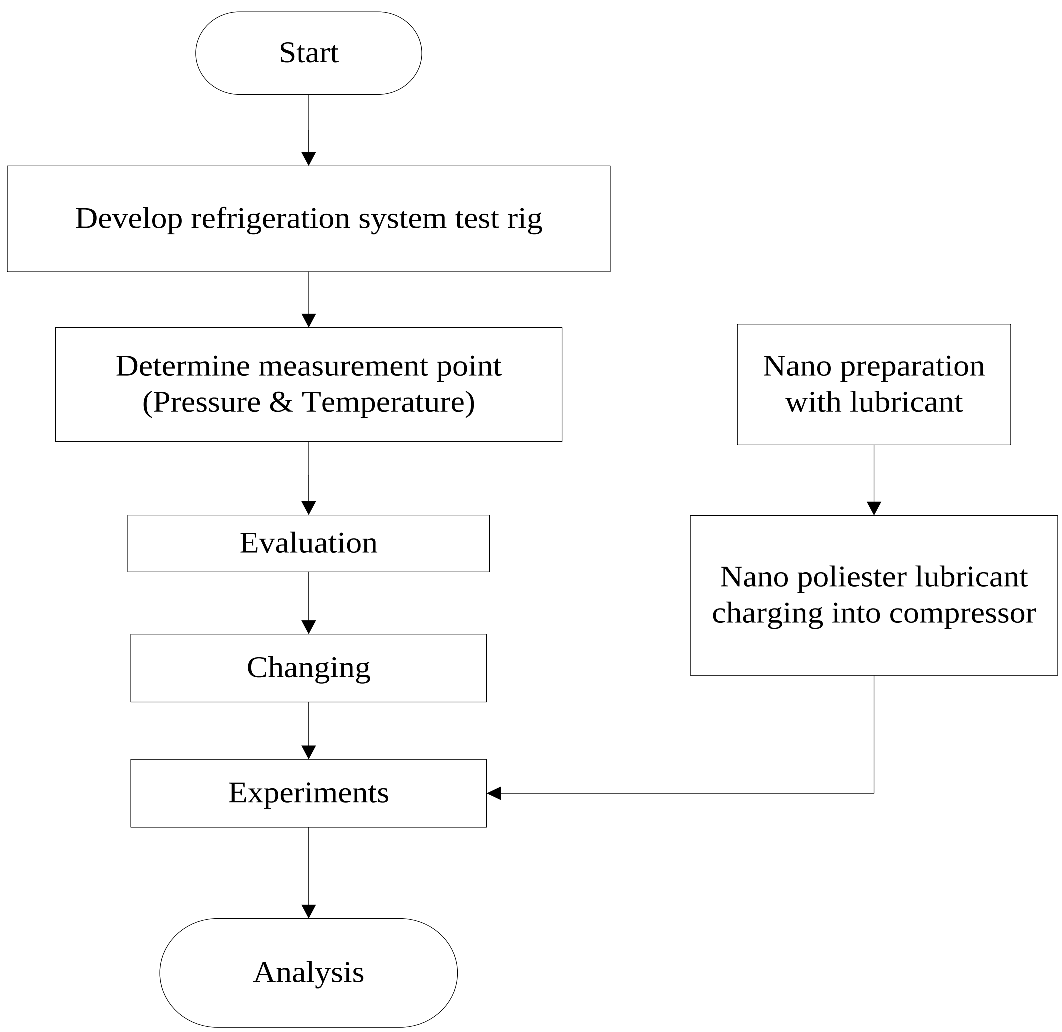


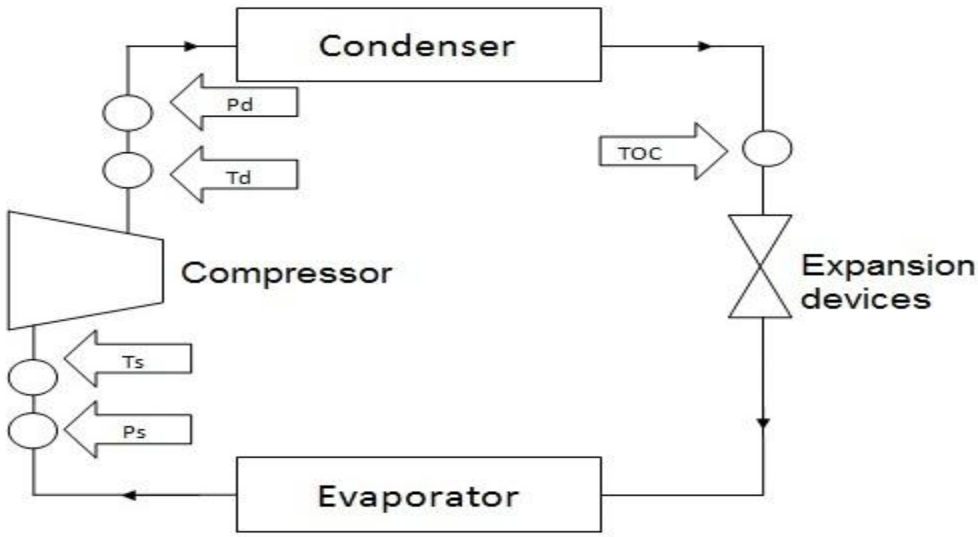
Figure 3.2: Experiment flow chart.

3.2 TEST RIG DEVELOPMENT

The development method and measurement locations of pressure and temperature are very important to ensure that the test rig can produce correct data. There are three points of temperature measurements, two points of pressure measurements.

3.2.1 Temperature and Pressure Measurement

Figure 3.3 shows the schematic diagram of minibar refrigeration system with the measurement devices are located. Where Ts indicates the thermocouple located at the compressor suction, Td indicated the thermocouple located at compressor discharged, Tca indicated the thermocouple located at capillary tube inlet, Ps indicated the pressure transducer located at compressor suction and Pd indicates the pressure located at compressor discharged.



Ts- Thermocouple at suction
Td- Thermocouple at discharge
Tca- Thermocouple at capillary tube inlet
Ps- Pressure gauge at suction
Pd- Pressure at discharge

Figure 3.3: Locations of measuring device in the refrigeration system.

3.3 SYSTEM EVACUATION

Evacuation is a process to remove the unwanted or non-condensable gases, air and the water vapour from the refrigeration system at the same time pulling a vacuum in the refrigeration system with vacuum pump. Those of these substances mentioned are detrimental to the system. This contaminant would come into the system when the system is assembled or service. The non- condensable gas like nitrogen will have occupied the condenser space when it moves through the condenser like liquid refrigerant, because of that it will make discharge temperature and compression ratio increase and cause unwanted in efficiency. The oxygen in the air will react with the refrigeration oil to form organic solid. Whereas the water vapour will react with R-134a which is contain either chlorine or fluorine to form acids and more water. Acids that formed will cause metal corrosion and sludge can produce inside the system (Whitman 2005). That why evacuating the refrigeration system is essential to ensure system can operate longer and efficient.

In reality, perfect vacuum has never been achieved, however there are instrument that can approach to the perfect vacuum. Before charging the system, checking on the system leaking is necessary .This is important because leakage will allows air to enter to the system during evacuation process and it also allows refrigerant to leak out from the system.

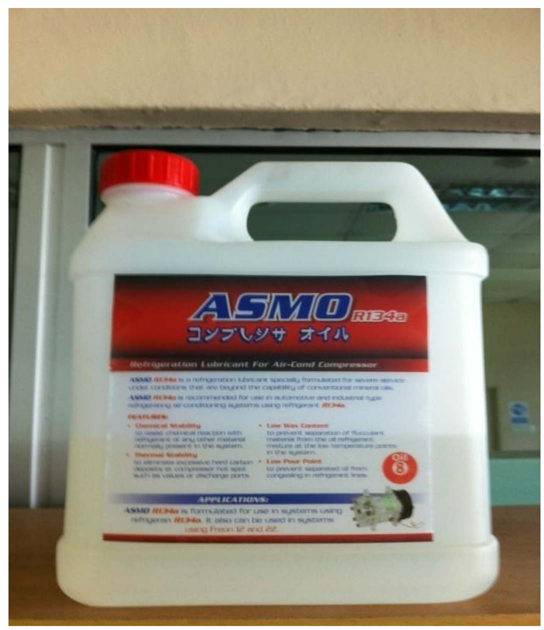
3.3.1 Equipment

In order to do evacuation processes, there is some equipment that needs to be use. There are some important devices that had been used, such as vacuum pump, and charging fold is use. Figure 3.4 show the equipments that needed in this experiment.

(a)

(b)

(c)



(d)

Figure 3.4: Equipment that used in experiment: (a) Refrigerant R134a cylinder tank,(b) Vacuum pump, (c) Charging manifold, (d) Compressor lubricant oil.

3.3.2 Evacuation Process Procedure

a) There are three ports at charging manifold. Right port is connected to the charging port at the compressor, the middle port is connected to the vacuum pump.
b) Open the valve.
c) Checked all connection properly.
d) Switched 'ON' the vacuum pump
e) Check the low pressure gauge at the charging manifold until vacuum is indicated
f) Switched 'OFF' the vacuum pump and check the system whether the pressure rises or not.
g) If the pressure does rise and stop at one point, it means some material such as water is boiling in the system. If this occurs, continue the evacuation by switch 'ON' the vacuum pump once again.
h) Stop the vacuum pump when the low pressure gauge at manifold shows the vacuum once again.
i) If the pressure continues to rise, that means there is a leak. The system should be check and fixed. Check the leakage by using soap bubbles. Put the soap bubbles throughout on the tubing system. If there is a leak, it will be easily detected by observing the soap bubbles.
j) Switch 'ON' the vacuum pump, and the system evacuation process is completed. The system is ready for refrigerating charging.

As mentioned before this, the most common used equipment for evacuation is vacuum pump and charging manifold. Sometimes the equipment is integrated into one called charging set which was used in this research. Figure 3.5 shows the schematic diagram of evacuation process.

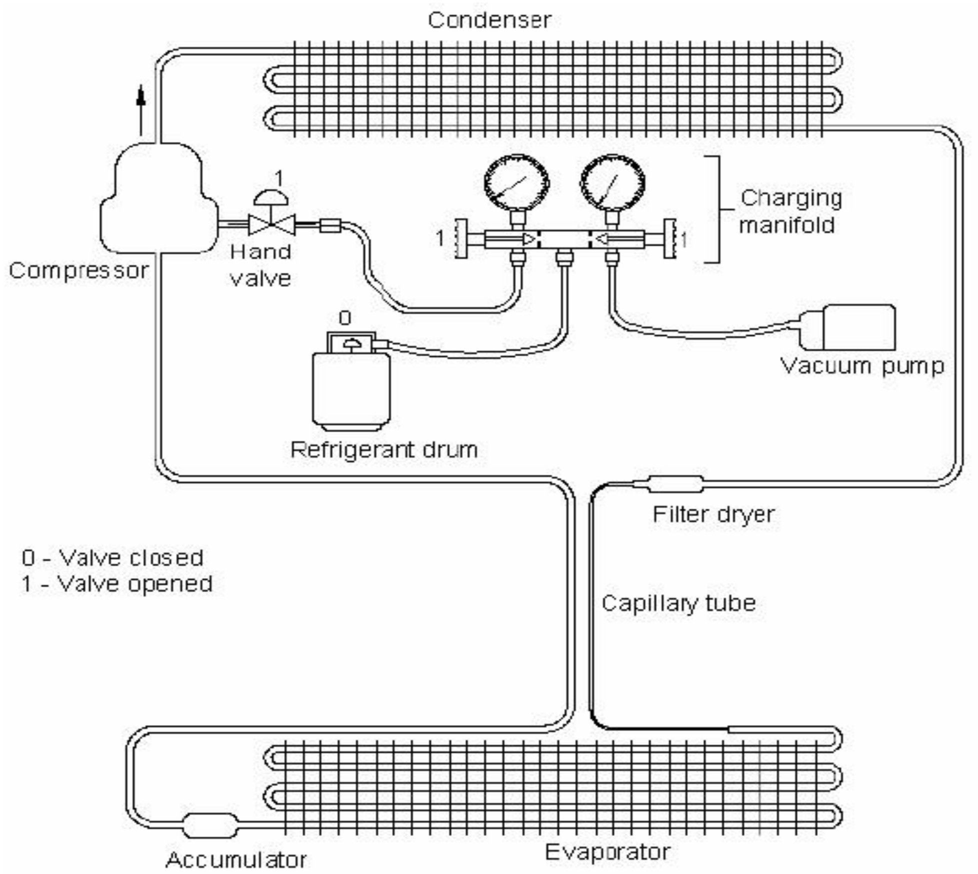


Figure 3.5: Schematic diagram of evacuation process.
Source: Yusof Taib (2005)

3.4 SYSTEM CHARGING

System charging is a process to add the refrigerant to the system and it must be charge correctly and added to the system to ensure refrigeration system can operate well as it was designed. The correct amount of charge is also depending on the operation temperature and the pressure of the system which had been designed. Refrigerant can be added to the system in vapour or liquid state by weighting, measuring or using operation chart.

In this refrigeration system R134a will be used by the mean of vapour refrigerant charging. Refrigerant in form vapor will be charged into the refrigeration system from high pressure side charging port of compressor. Liquid refrigerant charging normally accomplished in the liquid line such as charge into the king valve receiver (Whitman 2005). The refrigeration system test rig is being charged with R-134a. The procedure to charge the refrigerant vapour is described below with the aid of Figure 5.6.

a) Disconnect the middle port from the vacuum pump.
b) Connect the middle port of charging manifold to the refrigerant cylinder tank
c) The right port of the charging manifold still at the compressor as mentioned early.
d) Open the manifold valve at the refrigerant cylinder tank while the right charging manifold valve remaining closed. Leave the cylinder for 10 second.
e) Slowly open the right side manifold valve until the pressure reach 35 psi and wait for the refrigerant travels through the capillary tube into the low side pressure. The pressure of high pressure side will gradually decrease while the pressure at the low side will increase, and it will be equalizes each other.
f) Repeat the process when the high and low side pressure equal about 0 and 10 psi and allow the system to equalize until the static pressure of the system is about 35 psi.
g) Turn ‘ON’ the compressor, observation of the high side pressure gauge should show the rises to region 160 and 190 psi depending on the component of the system and the ambient temperature. The low side pressure can be observed decrease to slight vacuum and again it will also depends to the component of the system.

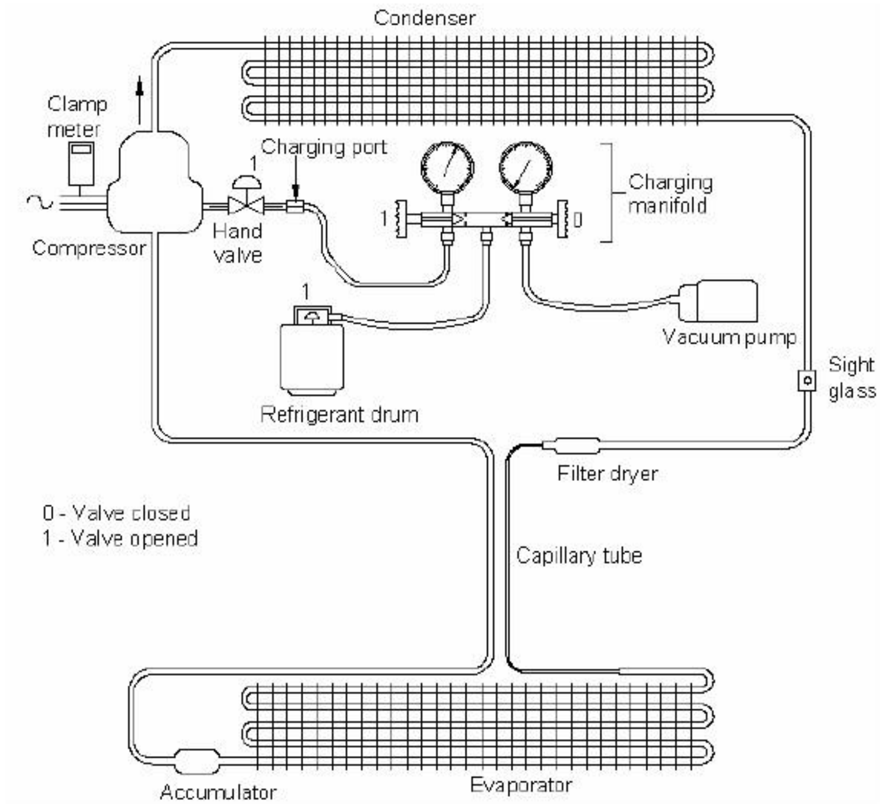


Figure 3.6: Configuration of system during refrigerant charging.

Source: Yusof Taib (2005)

3.5 SAMPLE OF NANOFLUID PREPARATION

The term 'nanofluid', meaning a two-phase mixture usually consists of nanoparticles dispersed in common liquids. There are two techniques to produce nanofluid which is single step and two step techniques but most of nanofluids containing oxide nanoparticles and carbon nanotube is produce by the two step techniques.

In this project, nanofluids are prepared by two step techniques which dispersing the nanoparticles in a base fluid which is oil, proper mixing, and stabilization of the particles. There are three methods used to attain stability of suspension against sedimentation of nanoparticles, and these are summarized as follows:

i. Control of ph value of the suspensions.
ii. Addition of surface activators or surfactants (Sodium Dodecyl Benzene Sulfonate – SDBS).
iii. Use of magnetic stirrer for continuously mixture.

A CNT and Alumina nanoparticle with average diameter size of 50 nm and 13 nm is used to prepare the nanolubricant. Nanoparticles are added after the dispersant is mixed with lubricant around tenth minutes. The mixture is stirred with magnetic stirrer continuously for 30 minutes. The desired volume concentrations used in this study are 0.2%.

3.6 EXPERIMENT

In this experiment section, sample of nanofluid that were prepared in the pre-experiment which is CNT and ALUMINA dilute by oil (lubricant) as a based fluid at five volume concentration 0.2%. Step by step of running experiment are as follow:

1. Sample one of nanofluids is placed in the compressor before experiment is running.
2. Power supply is on to operate the minibar refrigeration system.
3. Let the system reach the steady condition, at least one hour.
4. Related data is taken.
5. Repeat step 1 to 4 for at least ten times with different days.
6. After fifth times collecting data, do the analysis.
7. When the experiment completed for sample one, compressor need to be make sure no nanofluid sample one is left inside.
8. Step 1 to 7 is repeated for another sample of nanofluids.

3.7 ANALYSIS

Method use to analyze the data is conventional method, which is used the P-H diagram. In the analysis ideal vapour compression will used as references to find the enthalpy from each point has been measured. At the suction point the temperature and the pressure will used to find the enthalpy at this point. For point two or discharge point the pressure measured and the entropy from suction point will used as references to find the enthalpy at this point and enthalpy at point four and three will be same. This method follows the ideal vapour compression cycle. Figure 3.7 below can be used as a reference for this calculation.

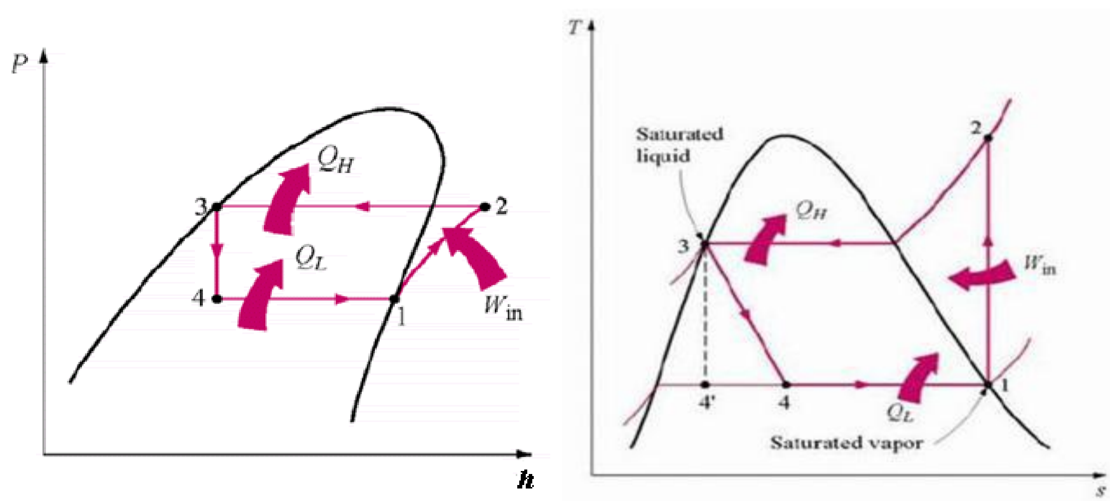


Figure 3.7: *P-h* and *T-s* Diagram of Vapor Compression Refrigeration Cycle.
Source: Cengel and Boles, 1998

After we get the value of enthalpy for each point, we will measure the efficiency of the refrigeration system by using coefficient of performance (COP) equation. COP is defined as ratio heat removed by the evaporator to the net work done by the compressor.

$$Cop = \frac{h1-h4}{h2-h1}$$

We will compare COP value that we get from both current refrigerants R-134a and nano-refrigerant in order to show that there is different energy consumption between them.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will present about the experiment analysis result from the beginning of the experiment until the end of the performance analysis. All data from the experiment will be calculated then will be presented as non dimensionless result and graph. Discussion and comparison in term of the relationship of enhancement heat transfer when different nanolubricant that used in refrigeration system also is highlighted in chapter. In this chapter also, discussion about the dispersion stability of nanofluids is considered.

In this study, normal lubricant R-134A, nano-lubricant carbon nanotubes (CNT) and nano-lubricant alumina with 0.2 % volume concentration are tested in refrigeration system. The purpose of the experiment is to analyze performance of mini bar refrigerator by introducing different lubricant oil into the refrigeration system.

The thermo physical properties needed for data analysis are specific heat, density, thermal conductivity and dynamic viscosity. These properties are temperature-dependent and vary with the type and volume concentrations. Parameter of interest that will be discussed in this chapter is the W_{in} which is work done by the compressor, heat rejected by the condenser Q_H, refrigerant effect Q_L and the refrigeration coefficient of performance, COP_R of the refrigeration system.

4.2 DATA COLLECTION FROM EXPERIMENT

The temperature and the pressure were collected at the locations for each of the points from the refrigeration system, which is at the suction, discharge of the compressor and before capillary tube for temperature. Pressure measurement is taken at two points which at suction and discharge of the compressor. The data collected was recorded in Table 4.1 until 4.3. The experiment conducted with different lubricant with amount 190 ml which is by same initial charging pressure of 35 psi.

Table 4.1: Temperature and pressure reading at for Poly-ester lubricant.

Date	Time	Pressure Suction (CM HG)	Pressure Discharge (PSI)	Temperature SuctionT1 (C)	Temperature DischargeT2 (C)	Temperature CondenserT3 (C)	Temperature Refrigerator (C)
03/11/2011	1540	10	165	35	62	42	30
14/11/2011	1405	05	170	34	62	42	30
15/11/2011	1405	05	170	34	62	42	30
16/11/2011	1400	05	170	35	64	42	30
17/11/2011	1405	10	165	35	62	42	30
Average		7	168	34.6	62.4	42	30

Table 4.2: Temperature and pressure reading for Nanolubricant CNT.

Date	Time	Pressure Suction (CM HG)	Pressure Discharge (PSI)	Temperature SuctionT1 (C)	Temperature DischargeT2 (C)	Temperature CondenserT3 (C)	Temperature Refrigerator (C)
07/02/2012	1425	25	125	36	59	43	25
08/02/2012	1430	25	125	35	57	43	25
09/02/2012	1430	25	125	35	56	42	25
10/02/2012	1430	25	125	35	58	43	25
11/02/2012	1550	25	125	35	56	43	25
Average		25	125	35.2	57.2	42.8	25

Table 4.3: Temperature and pressure reading at for Nanolubricant Alumina

Date	Time	Pressure Suction (CM HG)	Pressure Discharge (PSI)	Temperature SuctionT1 (C)	Temperature DischargeT2 (C)	Temperature CondenserT3 (C)	Temperature Refrigerator (C)
23/02/2012	1400	30	127	37	55	41	28
24/02/2012	1200	30	125	36	54	40	28
25/02/2012	1400	30	125	36	54	40	29
27/02/2012	1400	30	125	36	51	40	29
28/02/2012	1400	30	125	37	50	39	29
Average		30	125.4	36.4	52.8	40.0	28.6

4.2.1 Data Analysis

In order to determine thermodynamic properties of the refrigerant R-134a with normal lubricant and nanolubricant so we need to analyze data. The method used is the conventional method which is use the P-h diagram to find the enthalpy or use the Thermodynamics table R-134a. Both of this method can be use to achieve our goal in this project.

P-h diagram for refrigerant-134a is used to determine the enthalpy at each point in order to obtain the compressor work, heat rejection, heat rises and the coefficient of performance. Basically the enthalpy value at each point is determined based on a combination of pressure and temperature.

In this analysis, the theory of an ideal vapor compression cycle is used as a reference for determining the enthalpy at point ‘2’ and point ‘4’. At point ‘2’,isentropic process of compression is usual the entropy at point ‘1’ which is equal to enthalpy at point ‘2’ , and enthalpy at point ‘3’ is equal to enthalpy at point ‘4’ as show in Figure 2.1. The detailed of calculation is showed in the following section.

4.2.2 Data and Calculation

Calculation of parameter of interest is taken at average reading of the temperature & pressure after steady state condition for initial charging pressure of 35 psi. The following calculation is obtained for refrigeration system working with R-134a- Poliester lubricant, R-134a- $Al_2 0_3$ poliester lubricant and R-134a-CNT polyester.

Refrigeration system with normal lubricant:

Compressor work: W_{in} = $(h_2 - h_1)$ = (342–280) kJ/*kg*

Heat rejected: $Q_H = (h_2 - h_3)$ = (342 – 167.7) *kJ/kg*

Heat picked up: Q_L $(h_1 - h_4)$ = (280 – 167.7) *kJ/kg*

Coefficient of performance: $COP_R = \frac{h_1 - h_4}{h_2 - h_1} = \frac{112.3}{62}$

Refrigeration system with alumina nano lubricant:

Compressor work: w_{in} = $(h_2 - h_1)$ = (336–278) kJ/*kg*

Heat rejected: $Q_H = (h_2 - h_3)$ = (336– 158) *kJ/kg*

Heat picked up: Q_L $(h_1 - h_4)$ = (278 – 158) *kJ/kg*

Coefficient of performance: $COP_R = \frac{h_1 - h_4}{h_2 - h_1} = \frac{120}{58}$

Refrigeration system with Carbon nanotube (CNT) lubricant

Compressor work: w_{in} = $(h_2 - h_1)$ = (342–279) kJ/*kg*

Heat rejected: $Q_H = (h_2 - h_3)$ = (342 – 155) *kJ/kg*

Heat picked up: Q_L $(h_1 - h_4)$ = (279 – 155) *kJ/kg*

Coefficient of performance: $COP_R = \frac{h_1 - h_4}{h_2 - h_1} = \frac{124}{63}$

Table 4.4 summarizes calculation result for each experiment with different lubricant oil.

Table 4.4: Summary of enthalpy and parameter of interest for different lubricant Enthalpy (h_1), (h_2), (h_3) and (h_4), Compressor work (w_{in}), Heat rejected (Q_H), Heat picked up (Q_L), COP_R at 35 psi initial charging

Type of lubricant	h_1 *kJ/kg*	h_2 *kJ/kg*	$h_3 = h_4$ *kJ/kg*	w_{in} *kJ/kg*	Q_H *kJ/kg*	Q_L *kJ/kg*	COP_R
R-134A lubricant	280	342	167.5	62	174.3	112.3	1.81
CNT lubricant	279	342	155	63	187	124	1.96
Alumina lubricant	278	336	158	58	178	120	2.06

The result of calculation for each experiment with different refrigerant charge is plotted in Figure 4.1 Figure 4.2 and Figure 4.3. Figure 4.1, 4.2 and 4.3 shows average pressure versus enthalpy.

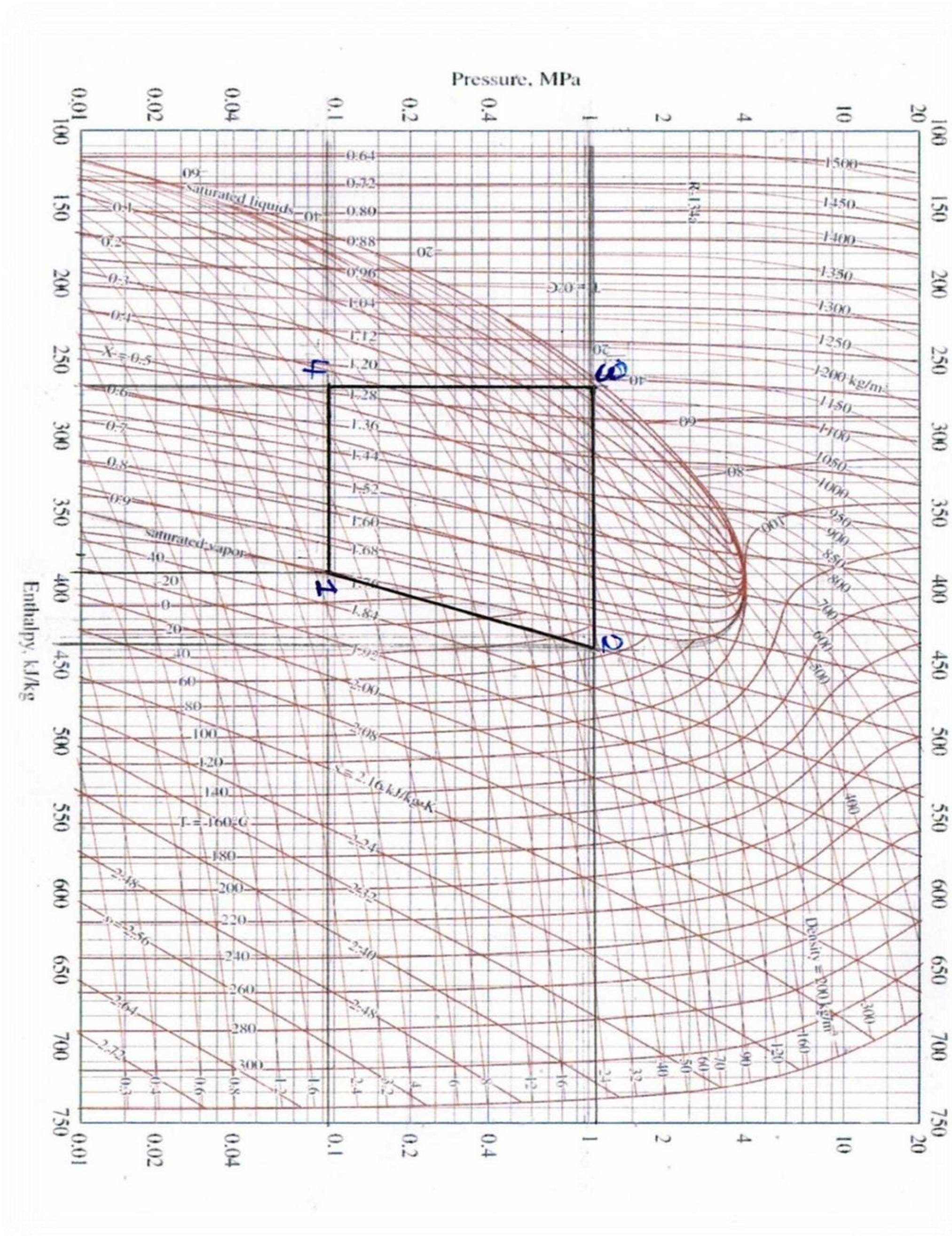


Figure 4.1: Pressure versus Enthalpy for Poly-ester lubricant (R-134A lubricant)

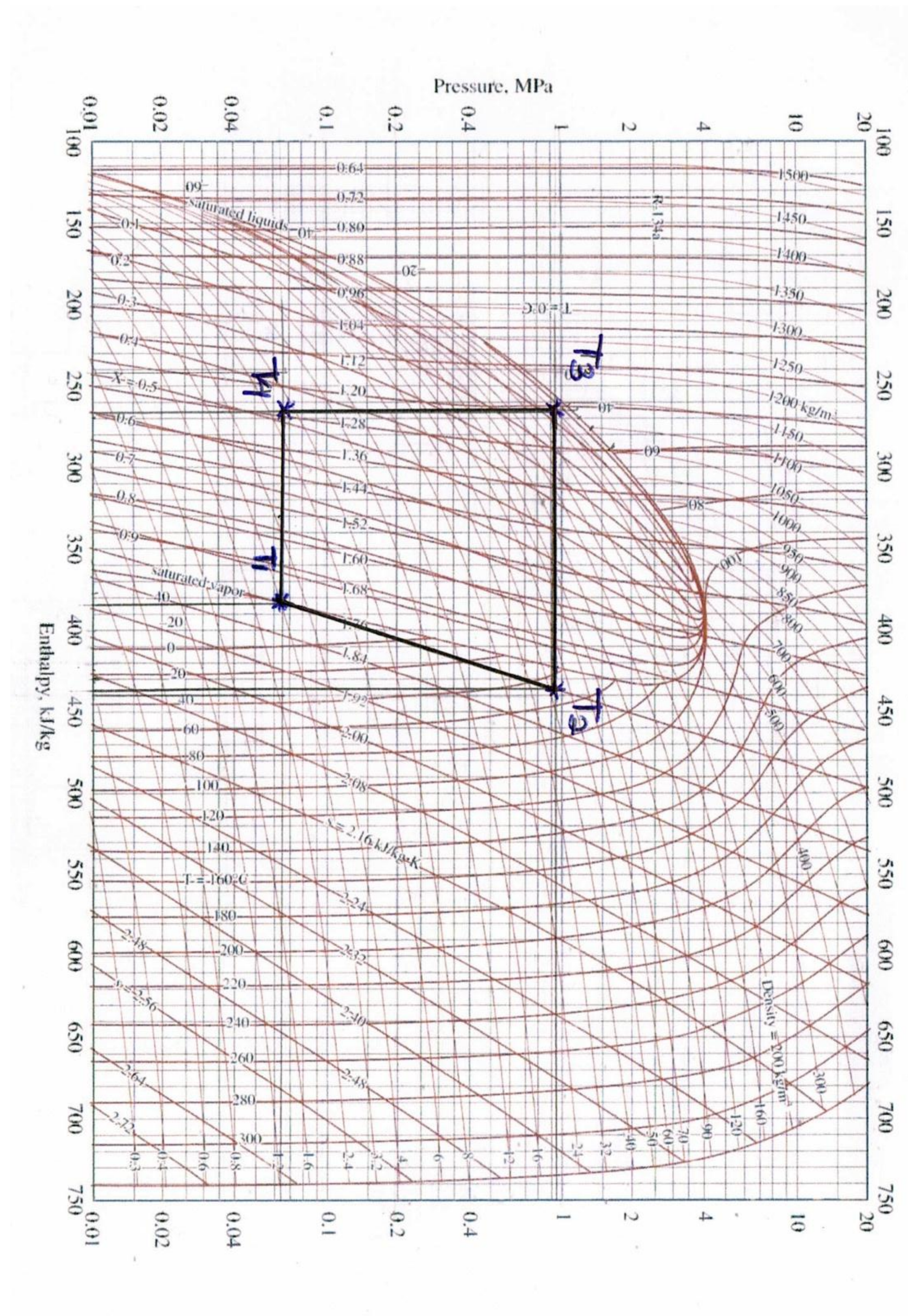


Figure 4.2: Pressure versus Enthalpy for Carbon nanotube lubricant

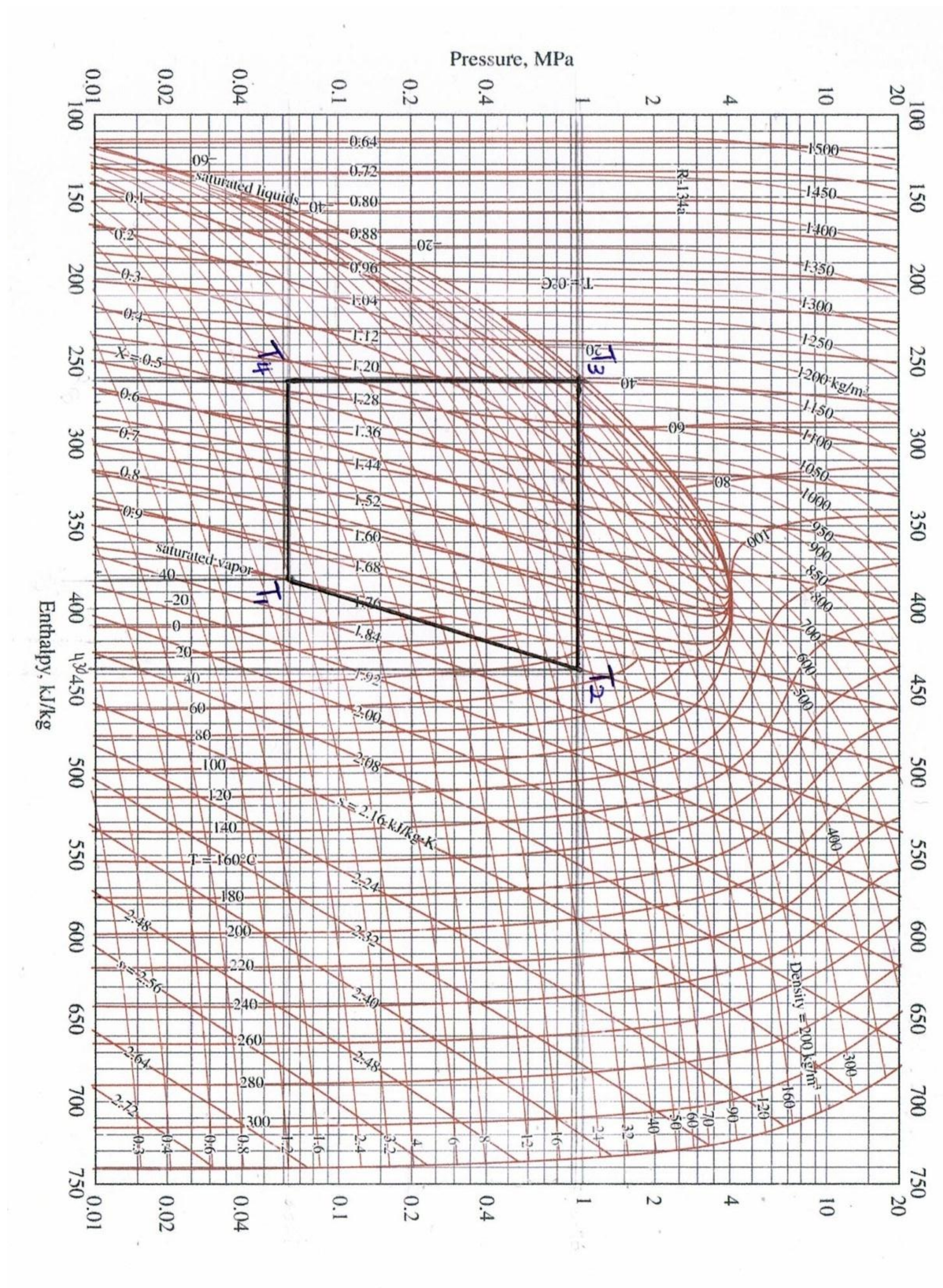


Figure 4.3: Pressure versus Enthalpy for Alumina nano lubricant

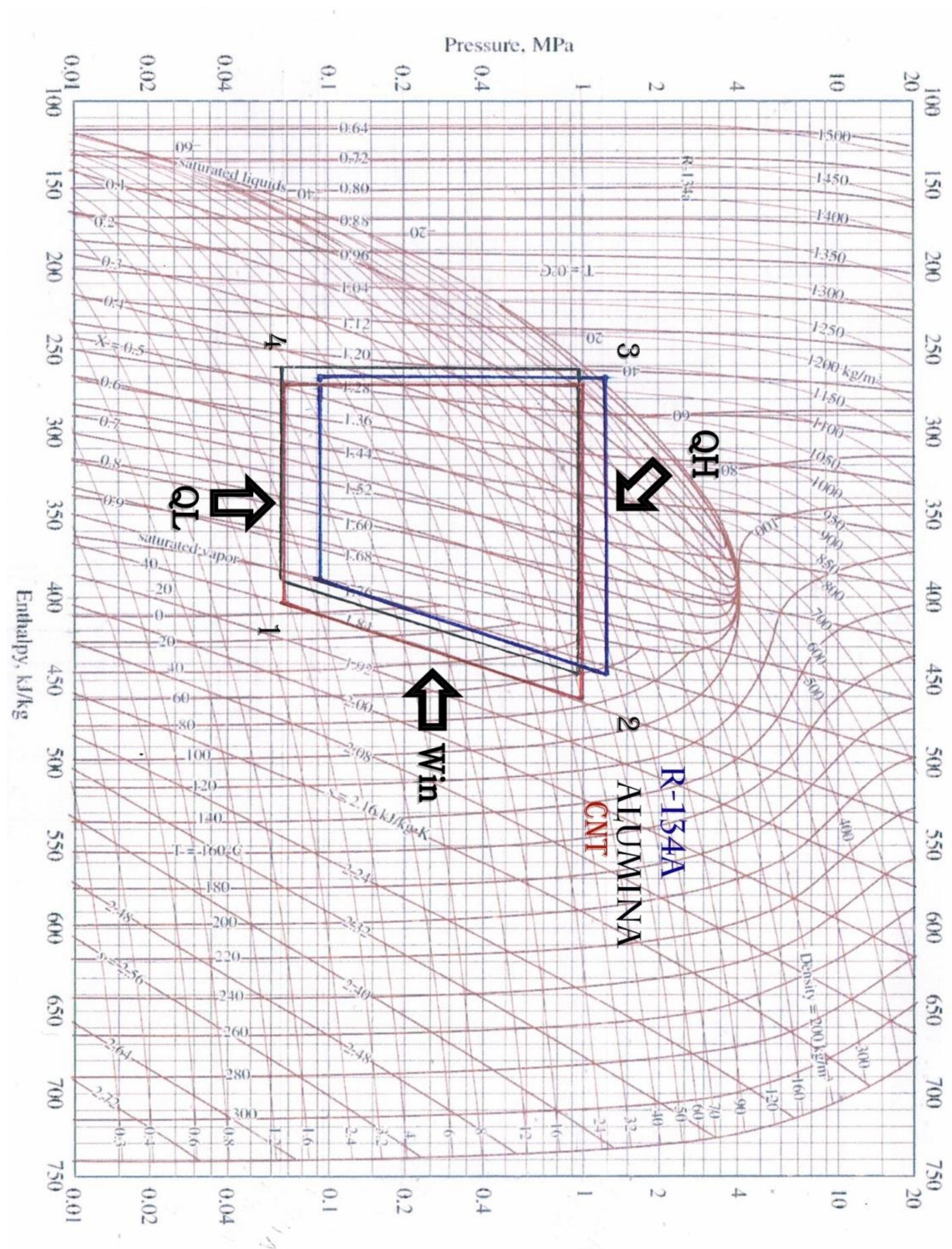


Figure 4.4: Combination of graph Pressure versus Enthalpy for all lubricant.

Based on Table 4.1, 4.2 and 4.3, the data show the highest average suction pressure is Alumina lubricant with 30 cm hg, followed by CNT lubricant with 25 cm hg and the highest is poly-ester (normal r134a refrigeration lubricant) with 7 cm hg. As explained in literature part, theory said that the higher suction pressure to give denser gas entering the compressor and therefore a greater mass of gas for a given swept volume, and so a higher refrigerating duty. Meanwhile the higher suction pressure, so a lower compression ratio that we will have and of course because of lower compression ratio system will use less power for a given duty.

Based on that table also, the data show the average lowest discharge pressure is CNT lubricant with 125 psi, 125.4 psi for Alumina lubricant and for poly-ester lubricant is 168 psi. With lowest discharge pressure it also will decrease the compression ratio and power uses by the system.

From data of suction and discharge pressure that have been compared above, it can be concluded that refrigeration system with nanolubricant give result more efficient compared to normal lubricant R-134A in term of work done and power uses by compressor and between nano lubricant, Alumina lubricant is better than CNT lubricant in term of high suction pressure meanwhile CNT lubricant is better than Alumina lubricant in term of discharge pressure.

Heat rejected (Q_H) happen in condensation process, this process is changing a vapour into a liquid by extracting heat. The higher the heat that has been removed, the liquid phase occurs move faster. From experiment that have been conducted, (referr to figure 4.4), the higher heat rejected is Carbon nanotube lubricant with 187 kj/kg followed by Alumina lubricant with 178 kj/kg and the last one is R-134A lubricant with 174.3 kj/kg. Once again, have been proved that in term of heat rejected (Q_H), nanolubricant is better than normal R-134A lubricant. Comparison between nanolubricant, CNT is better than Alumina in term of heat rejected (Q_H).

The performance of the refrigerator is determined by performance of heat absorbed,Q_L divided by Compressor work,w_{in}, the higher the heat that has been absorbed and lowest work in will give the highest performance of the refrigeration system. From data that have been discussed, the lowest compressor work is goes to Alumina lubricant and the heat absorbed produced by refrigeration system with Alumina lubricant is slightly lower than the highest value that produced by CNT lubricant. From that data, it can be concluded that coefficient of performance for refrigeration system working with alumina lubricant oil is the highest with 2.06, followed by CNT lubricant oil with 1.96 and the lowest is normal refrigeration R-134A lubricant oil with 1.81.

4.3 DISPERSION STABILITY OF NANOFLUIDS

Long term stability of nanoparticles dispersion is one of the basic requirements of nanofluids applications. Stability of nanofluids have good corresponding relationship with the enhancement of thermal conductivity where the better dispersion behaviour, the higher thermal conductivity of nanofluids [Wen D, 2009]. Because of this issue, the dispersion nanoparticles between Alumina and Carbon nanotube have been studies. Figure 4.5 until 4.11 shows the dispersion stability of the nanoparticles every one hour with white colour is alumina lubricant oil and the black colour is CNT lubricant oil.

Figure 4.5 shows initial condition of nanolubricant after stir, this figure taken at 10.10 AM. Figure 4.6 is taken after 1 hour nanolubricant being stir and its show bond between the nanoparticles and lubricants are still strong. Alumina lubricant starts to have changes in term of colour from bright to white blur, this situation have been showed in figure 4.7. Figure 4.8 is after 3 hour stir, Alumina start to begin to settle to the bottom. CNT also got changes in their properties, but because of the dark colour the change is not so noticeable. Figure 4.11 showed the condition of nanolubricant after 20 hour stir. After a week, precipitation process took place nearly 98%, most of the particles have settled to the bottom, this condition of nanolubricant can be seen in figure

4.12. Figure 4.13 show the precipitation process has reached the maximum, there is no change in precipitation after 3 hours.

Figure 4.5: Dispertion stability after stir.
(25/4/2012 10:10 AM)

Figure 4.6: Dispertion stability after 1 hour stir.
(25/4/2012 11:26 AM)

Figure 4.7: Dispertion stability after 2 hour stir.
(25/4/2012 12:57 PM)

Figure 4.8: Dispertion stability after 3 hour stir.
(25/4/2012 01:36 PM)

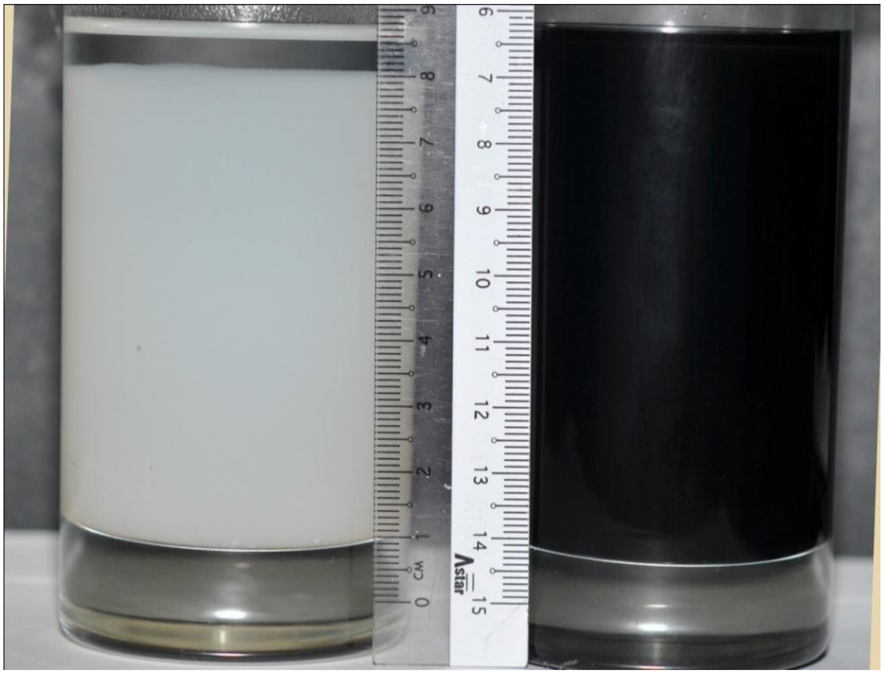


Figure 4.9: Dispertion stability after 8 hour stir.
(25/4/2012 05:43 PM)

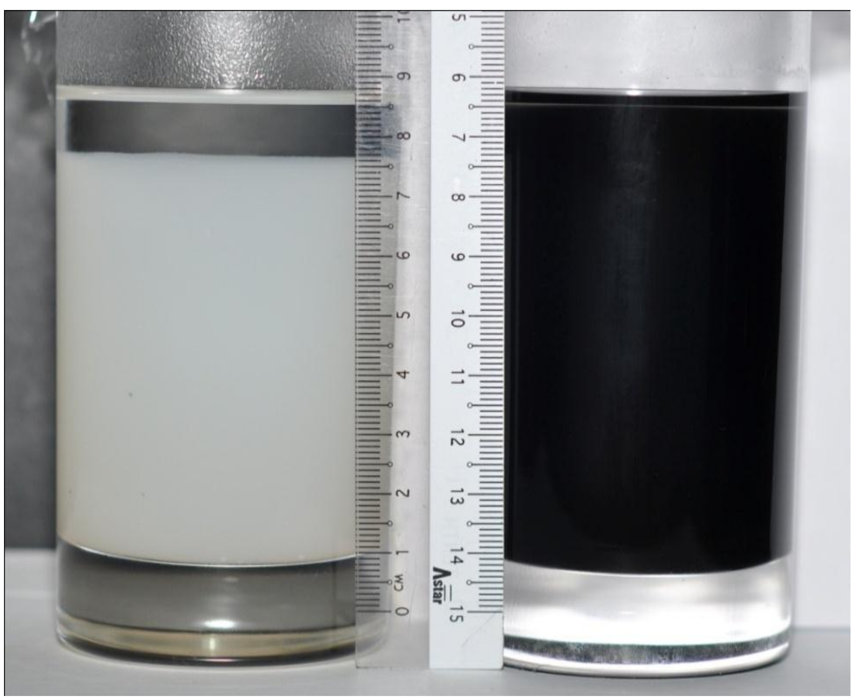


Figure 4.10: Dispertion stability after 13 hour stir.
(25/4/2012 10:22 PM)

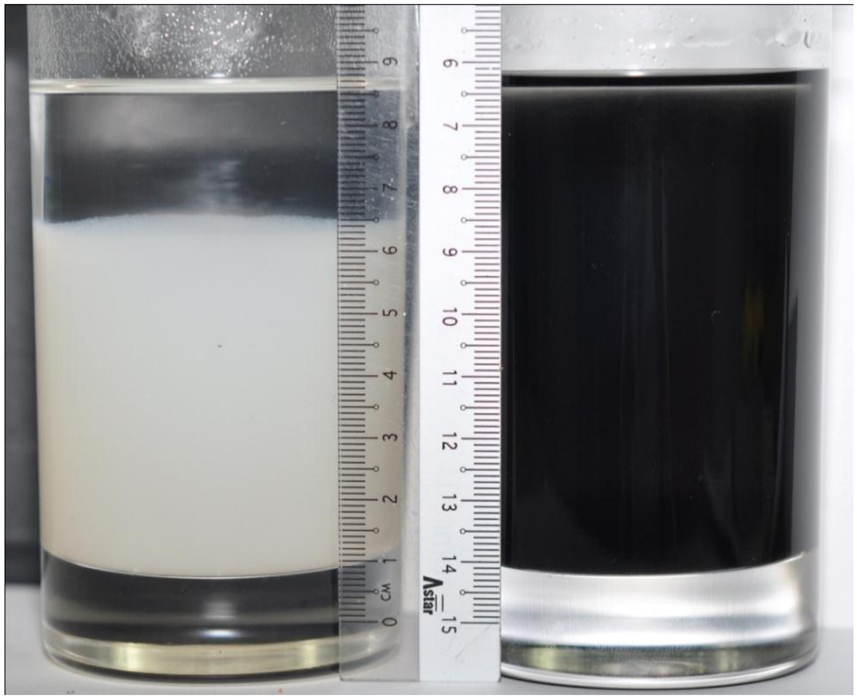


Figure 4.11: Dispertion stability after 20 hourstir
(26/4/2012 05:25 AM)

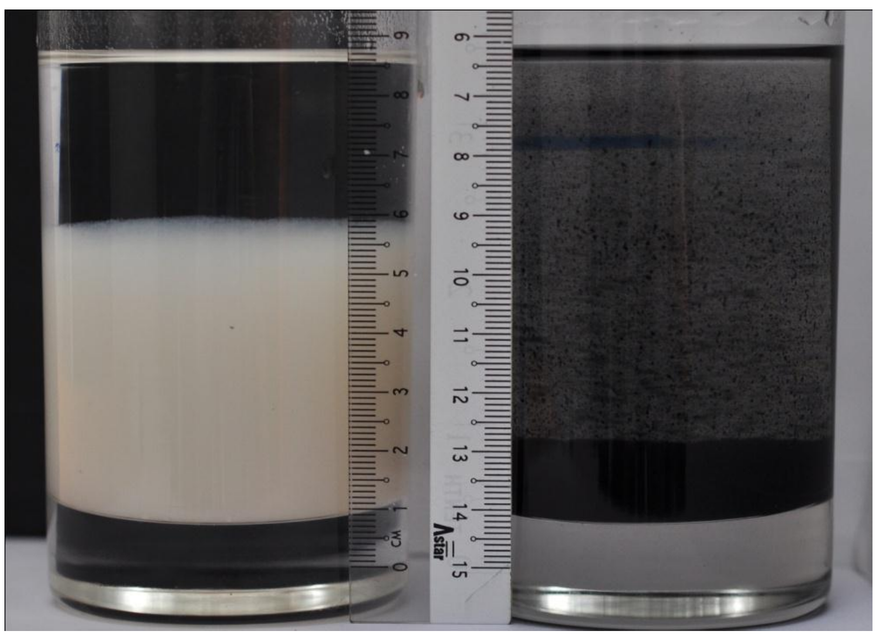


Figure 4.12: Dispertion stability after 149 hour stir
(01/05/2012 10:47 AM)

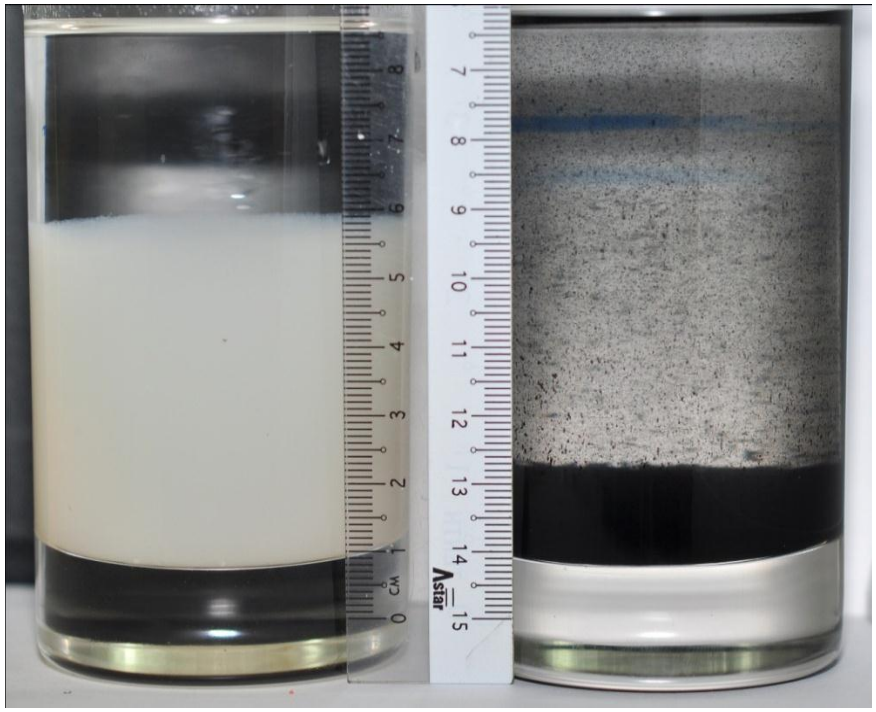


Figure 4.13: Dispertion stability after 154 stir
(01/05/2012 03:00 PM)

In conclusion, both nanolubricant takes about a week to settle as a whole. Refrigeration system is a system that is always flowing and always chaos, so it's not a problem for nanoparticles as it will keep going and never settle. And if refrigeration systems need to close temporarily, it does not matter because both nanolubricant takes about a week to settle in full. So as a conclusion, Alumina and CNT particles suitable for use in lubricant oil.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The coefficient of performance, COP of refrigeration system with poly-ester lubricant oil and coefficient of performance, COP refrigeration system with Alumina nanolubricant and CNT nanolubricant with 0.2% volume concentration was investigated experimentally. The maximum enhancement in percentage of coefficient of performance between alumina lubricant oil and poly-ester lubricant is 13.8%, and between CNT nanolubricant and poly-ester lubricant is 8.29% was been recorded.

As a conclusion, the overall characterization of nanolubricant can be conclude that the additional of 0.2% volume concentration of nanoparticles can increased the performance of the refrigeration system. The objectives of the study have been achieved.

5.2 RECOMMENDATIONS

In order to get more precision result during this study, it needs some recommendations and adjustment especially in experiment apparatus used during the experiment for example thermocouple better measure temperature inside the tubing, this method can enhance the accuracy of the result.

Thermophysical properties of nanoparticles such as nanoparticles density need to be determined by experimental method compare to correlation that was obtained from previous researches in order to optimum the result accuracy.

Next, the suction pressure of refrigeration system for both with nanolubricant and with poly-ester lubricant needs to be set same in order to get most accurate data.

Lastly, the amount of data collection also must be increased to improve the accuracy of the data when made average. For future study I strongly recommend to directly study this topic by using high number of concentration.

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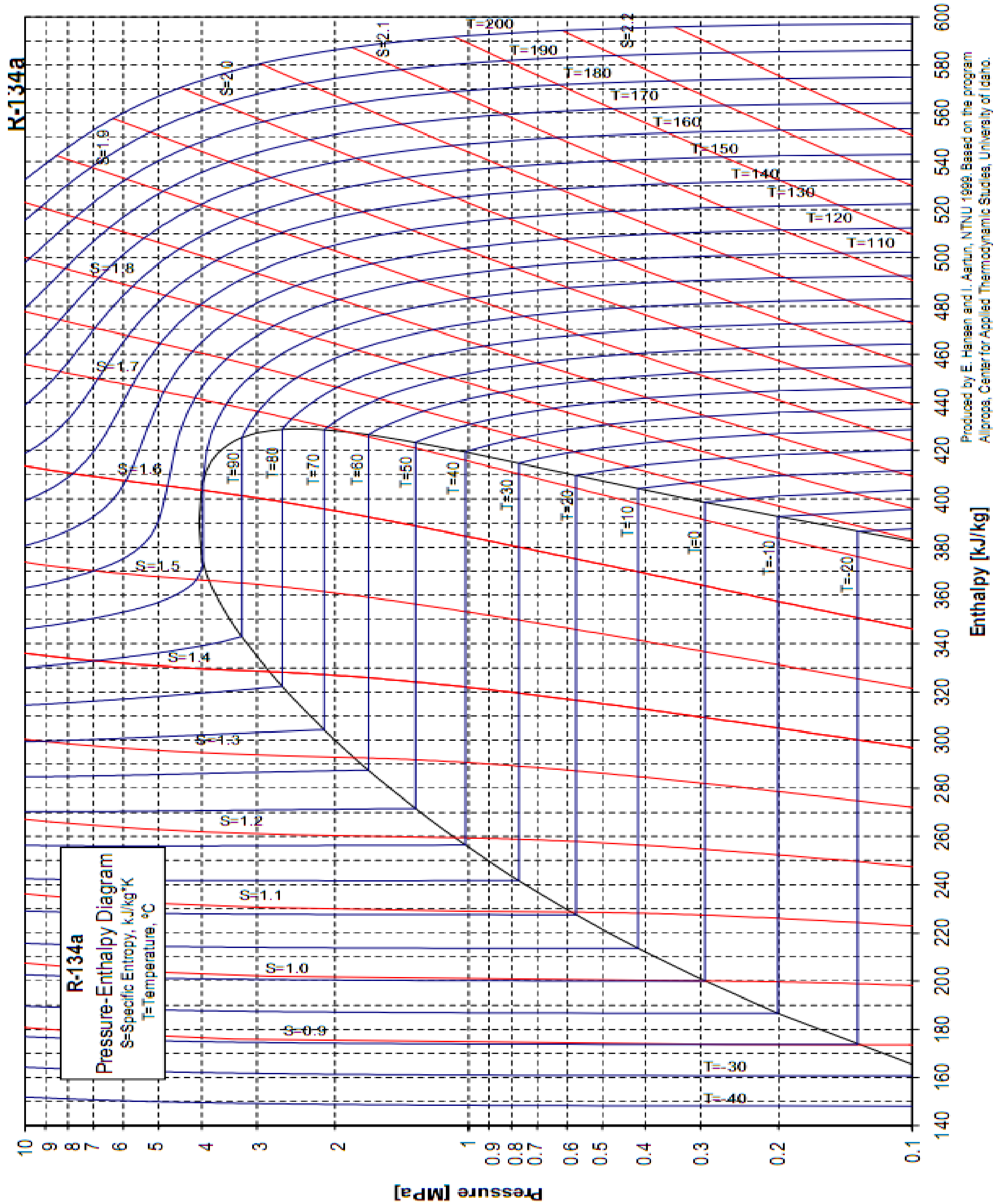
APPENDIX A

Pressure-Enthalpy (p - h) diagram for refrigerant 134a



APPENDIX B

R-134-a Table

TABLE A–11E

Saturated refrigerant-134a—Temperature table

		Specific volume, ft³/lbm		*Internal energy,* Btu/lbm			*Enthalpy,* Btu/lbm			*Entropy,* Btu/lbm·R		
Temp., T °F	Sat. press., P_{sat} psia	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
−40	7.432	0.01130	5.7796	−0.016	89.167	89.15	0.000	97.100	97.10	0.00000	0.23135	0.23135
−35	8.581	0.01136	5.0509	1.484	88.352	89.84	1.502	96.354	97.86	0.00355	0.22687	0.23043
−30	9.869	0.01143	4.4300	2.990	87.532	90.52	3.011	95.601	98.61	0.00708	0.22248	0.22956
−25	11.306	0.01150	3.8988	4.502	86.706	91.21	4.526	94.839	99.36	0.01058	0.21817	0.22875
−20	12.906	0.01156	3.4426	6.019	85.874	91.89	6.047	94.068	100.12	0.01405	0.21394	0.22798
−15	14.680	0.01163	3.0494	7.543	85.036	92.58	7.574	93.288	100.86	0.01749	0.20978	0.22727
−10	16.642	0.01171	2.7091	9.073	84.191	93.26	9.109	92.498	101.61	0.02092	0.20569	0.22660
−5	18.806	0.01178	2.4137	10.609	83.339	93.95	10.650	91.698	102.35	0.02431	0.20166	0.22598
0	21.185	0.01185	2.1564	12.152	82.479	94.63	12.199	90.886	103.08	0.02769	0.19770	0.22539
5	23.793	0.01193	1.9316	13.702	81.610	95.31	13.755	90.062	103.82	0.03104	0.19380	0.22485
10	26.646	0.01201	1.7345	15.259	80.733	95.99	15.318	89.226	104.54	0.03438	0.18996	0.22434
15	29.759	0.01209	1.5612	16.823	79.846	96.67	16.889	88.377	105.27	0.03769	0.18617	0.22386
20	33.147	0.01217	1.4084	18.394	78.950	97.34	18.469	87.514	105.98	0.04098	0.18243	0.22341
25	36.826	0.01225	1.2732	19.973	78.043	98.02	20.056	86.636	106.69	0.04426	0.17874	0.22300
30	40.813	0.01234	1.1534	21.560	77.124	98.68	21.653	85.742	107.40	0.04752	0.17509	0.22260
35	45.124	0.01242	1.0470	23.154	76.195	99.35	23.258	84.833	108.09	0.05076	0.17148	0.22224
40	49.776	0.01251	0.95205	24.757	75.253	100.01	24.873	83.907	108.78	0.05398	0.16791	0.22189
45	54.787	0.01261	0.86727	26.369	74.298	100.67	26.497	82.963	109.46	0.05720	0.16437	0.22157
50	60.175	0.01270	0.79136	27.990	73.329	101.32	28.131	82.000	110.13	0.06039	0.16087	0.22127
55	65.957	0.01280	0.72323	29.619	72.346	101.97	29.775	81.017	110.79	0.06358	0.15740	0.22098
60	72.152	0.01290	0.66195	31.258	71.347	102.61	31.431	80.013	111.44	0.06675	0.15396	0.22070
65	78.780	0.01301	0.60671	32.908	70.333	103.24	33.097	78.988	112.09	0.06991	0.15053	0.22044
70	85.858	0.01312	0.55681	34.567	69.301	103.87	34.776	77.939	112.71	0.07306	0.14713	0.22019
75	93.408	0.01323	0.51165	36.237	68.251	104.49	36.466	76.866	113.33	0.07620	0.14375	0.21995
80	101.45	0.01334	0.47069	37.919	67.181	105.10	38.169	75.767	113.94	0.07934	0.14038	0.21972
85	110.00	0.01347	0.43348	39.612	66.091	105.70	39.886	74.641	114.53	0.08246	0.13703	0.21949
90	119.08	0.01359	0.39959	41.317	64.979	106.30	41.617	73.485	115.10	0.08559	0.13368	0.21926
95	128.72	0.01372	0.36869	43.036	63.844	106.88	43.363	72.299	115.66	0.08870	0.13033	0.21904
100	138.93	0.01386	0.34045	44.768	62.683	107.45	45.124	71.080	116.20	0.09182	0.12699	0.21881
105	149.73	0.01400	0.31460	46.514	61.496	108.01	46.902	69.825	116.73	0.09493	0.12365	0.21858
110	161.16	0.01415	0.29090	48.276	60.279	108.56	48.698	68.533	117.23	0.09804	0.12029	0.21834
115	173.23	0.01430	0.26913	50.054	59.031	109.08	50.512	67.200	117.71	0.10116	0.11693	0.21809
120	185.96	0.01446	0.24909	51.849	57.749	109.60	52.346	65.823	118.17	0.10428	0.11354	0.21782
130	213.53	0.01482	0.21356	55.495	55.071	110.57	56.080	62.924	119.00	0.11054	0.10670	0.21724
140	244.06	0.01521	0.18315	59.226	52.216	111.44	59.913	59.801	119.71	0.11684	0.09971	0.21655
150	277.79	0.01567	0.15692	63.059	49.144	112.20	63.864	56.405	120.27	0.12321	0.09251	0.21572
160	314.94	0.01619	0.13410	67.014	45.799	112.81	67.958	52.671	120.63	0.12970	0.08499	0.21469
170	355.80	0.01681	0.11405	71.126	42.097	113.22	72.233	48.499	120.73	0.13634	0.07701	0.21335
180	400.66	0.01759	0.09618	75.448	37.899	113.35	76.752	43.726	120.48	0.14323	0.06835	0.21158
190	449.90	0.01860	0.07990	80.082	32.950	113.03	81.631	38.053	119.68	0.15055	0.05857	0.20911
200	504.00	0.02009	0.06441	85.267	26.651	111.92	87.140	30.785	117.93	0.15867	0.04666	0.20533
210	563.76	0.02309	0.04722	91.986	16.498	108.48	94.395	19.015	113.41	0.16922	0.02839	0.19761

Source: Tables A–11E through A–13E are generated using the Engineering Equation Solver (EES) software developed by S. A. Klein and F. L. Alvarado. The routine used in calculations is the R134a, which is based on the fundamental equation of state developed by R. Tillner-Roth and H.D. Baehr, "An International Standard Formulation for the Thermodynamic Properties of 1,1,1,2-Tetrafluoroethane (HFC-134a) for Temperatures from 170 K to 455 K and Pressures up to 70 MPa," *J. Phys. Chem, Ref. Data*, Vol. 23, No. 5, 1994. The enthalpy and entropy values of saturated liquid are set to zero at −40°C (and −40°F).

TABLE A–12E

Saturated refrigerant-134a—Pressure table

		Specific volume, ft³/lbm		Internal energy, Btu/lbm			Enthalpy, Btu/lbm			Entropy, Btu/lbm · R		
Press., P psia	Sat. temp., T °F	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}	Sat. vapor, s_g
5	−53.09	0.01113	8.3785	−3.918	91.280	87.36	−3.907	99.022	95.11	−0.00945	0.24353	0.23408
10	−29.52	0.01144	4.3753	3.135	87.453	90.59	3.156	95.528	98.68	0.00742	0.22206	0.22948
15	−14.15	0.01165	2.9880	7.803	84.893	92.70	7.835	93.155	100.99	0.01808	0.20908	0.22715
20	−2.43	0.01182	2.2772	11.401	82.898	94.30	11.445	91.282	102.73	0.02605	0.19962	0.22567
25	7.17	0.01196	1.8429	14.377	81.231	95.61	14.432	89.701	104.13	0.03249	0.19213	0.22462
30	15.37	0.01209	1.5492	16.939	79.780	96.72	17.006	88.313	105.32	0.03793	0.18589	0.22383
35	22.57	0.01221	1.3369	19.205	78.485	97.69	19.284	87.064	106.35	0.04267	0.18053	0.22319
40	29.01	0.01232	1.1760	21.246	77.307	98.55	21.337	85.920	107.26	0.04688	0.17580	0.22268
45	34.86	0.01242	1.0497	23.110	76.221	99.33	23.214	84.858	108.07	0.05067	0.17158	0.22225
50	40.23	0.01252	0.94791	24.832	75.209	100.04	24.948	83.863	108.81	0.05413	0.16774	0.22188
55	45.20	0.01261	0.86400	26.435	74.258	100.69	26.564	82.924	109.49	0.05733	0.16423	0.22156
60	49.84	0.01270	0.79361	27.939	73.360	101.30	28.080	82.030	110.11	0.06029	0.16098	0.22127
65	54.20	0.01279	0.73370	29.357	72.505	101.86	29.510	81.176	110.69	0.06307	0.15796	0.22102
70	58.30	0.01287	0.68205	30.700	71.688	102.39	30.867	80.357	111.22	0.06567	0.15512	0.22080
75	62.19	0.01295	0.63706	31.979	70.905	102.88	32.159	79.567	111.73	0.06813	0.15245	0.22059
80	65.89	0.01303	0.59750	33.201	70.151	103.35	33.394	78.804	112.20	0.07047	0.14993	0.22040
85	69.41	0.01310	0.56244	34.371	69.424	103.79	34.577	78.064	112.64	0.07269	0.14753	0.22022
90	72.78	0.01318	0.53113	35.495	68.719	104.21	35.715	77.345	113.06	0.07481	0.14525	0.22006
95	76.02	0.01325	0.50301	36.578	68.035	104.61	36.811	76.645	113.46	0.07684	0.14307	0.21991
100	79.12	0.01332	0.47760	37.623	67.371	104.99	37.869	75.962	113.83	0.07879	0.14097	0.21976
110	85.00	0.01347	0.43347	39.612	66.091	105.70	39.886	74.641	114.53	0.08246	0.13703	0.21949
120	90.49	0.01360	0.39644	41.485	64.869	106.35	41.787	73.371	115.16	0.08589	0.13335	0.21924
130	95.64	0.01374	0.36491	43.258	63.696	106.95	43.589	72.144	115.73	0.08911	0.12990	0.21901
140	100.51	0.01387	0.33771	44.945	62.564	107.51	45.304	70.954	116.26	0.09214	0.12665	0.21879
150	105.12	0.01400	0.31401	46.556	61.467	108.02	46.945	69.795	116.74	0.09501	0.12357	0.21857
160	109.50	0.01413	0.29316	48.101	60.401	108.50	48.519	68.662	117.18	0.09774	0.12062	0.21836
170	113.69	0.01426	0.27466	49.586	59.362	108.95	50.035	67.553	117.59	0.10034	0.11781	0.21815
180	117.69	0.01439	0.25813	51.018	58.345	109.36	51.497	66.464	117.96	0.10284	0.11511	0.21795
190	121.53	0.01452	0.24327	52.402	57.349	109.75	52.912	65.392	118.30	0.10524	0.11250	0.21774
200	125.22	0.01464	0.22983	53.743	56.371	110.11	54.285	64.335	118.62	0.10754	0.10998	0.21753
220	132.21	0.01490	0.20645	56.310	54.458	110.77	56.917	62.256	119.17	0.11192	0.10517	0.21710
240	138.73	0.01516	0.18677	58.746	52.591	111.34	59.419	60.213	119.63	0.11603	0.10061	0.21665
260	144.85	0.01543	0.16996	61.071	50.757	111.83	61.813	58.192	120.00	0.11992	0.09625	0.21617
280	150.62	0.01570	0.15541	63.301	48.945	112.25	64.115	56.184	120.30	0.12362	0.09205	0.21567
300	156.09	0.01598	0.14266	65.452	47.143	112.60	66.339	54.176	120.52	0.12715	0.08797	0.21512
350	168.64	0.01672	0.11664	70.554	42.627	113.18	71.638	49.099	120.74	0.13542	0.07814	0.21356
400	179.86	0.01757	0.09642	75.385	37.963	113.35	76.686	43.798	120.48	0.14314	0.06848	0.21161
450	190.02	0.01860	0.07987	80.092	32.939	113.03	81.641	38.041	119.68	0.15056	0.05854	0.20911
500	199.29	0.01995	0.06551	84.871	27.168	112.04	86.718	31.382	118.10	0.15805	0.04762	0.20566

TABLE A–13E

Superheated refrigerant-134a

T °F	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm · R	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm · R	*v* ft³/lbm	*u* Btu/lbm	*h* Btu/lbm	*s* Btu/lbm · R
	P = 10 psia (T_{sat} = −29.52°F)				P = 15 psia (T_{sat} = −14.15°F)				P = 20 psia (T_{sat} = −2.43°F)			
Sat.	4.3753	90.59	98.68	0.22948	2.9880	92.70	100.99	0.22715	2.2772	94.30	102.73	0.22567
−20	4.4856	92.13	100.43	0.23350								
0	4.7135	95.41	104.14	0.24174	3.1001	95.08	103.68	0.23310	2.2922	94.72	103.20	0.22671
20	4.9380	98.77	107.91	0.24976	3.2551	98.48	107.52	0.24127	2.4130	98.19	107.12	0.23504
40	5.1600	102.20	111.75	0.25761	3.4074	101.95	111.41	0.24922	2.5306	101.70	111.07	0.24311
60	5.3802	105.72	115.67	0.26531	3.5577	105.50	115.38	0.25700	2.6461	105.28	115.07	0.25097
80	5.5989	109.32	119.68	0.27288	3.7064	109.13	119.42	0.26463	2.7600	108.93	119.15	0.25866
100	5.8165	113.01	123.78	0.28033	3.8540	112.84	123.54	0.27212	2.8726	112.66	123.29	0.26621
120	6.0331	116.79	127.96	0.28767	4.0006	116.63	127.74	0.27950	2.9842	116.47	127.52	0.27363
140	6.2490	120.66	132.22	0.29490	4.1464	120.51	132.02	0.28677	3.0950	120.37	131.82	0.28093
160	6.4642	124.61	136.57	0.30203	4.2915	124.48	136.39	0.29393	3.2051	124.35	136.21	0.28812
180	6.6789	128.65	141.01	0.30908	4.4361	128.53	140.84	0.30100	3.3146	128.41	140.67	0.29521
200	6.8930	132.77	145.53	0.31604	4.5802	132.66	145.37	0.30798	3.4237	132.55	145.22	0.30221
220	7.1068	136.98	150.13	0.32292	4.7239	136.88	149.99	0.31487	3.5324	136.78	149.85	0.30912
	P = 30 psia (T_{sat} = 15.37°F)				P = 40 psia (T_{sat} = 29.01°F)				P = 50 psia (T_{sat} = 40.23°F)			
Sat.	1.5492	96.72	105.32	0.22383	1.1760	98.55	107.26	0.22268	0.9479	100.04	108.81	0.22188
20	1.5691	97.56	106.27	0.22581								
40	1.6528	101.17	110.35	0.23414	1.2126	100.61	109.58	0.22738				
60	1.7338	104.82	114.45	0.24219	1.2768	104.34	113.79	0.23565	1.0019	103.84	113.11	0.23031
80	1.8130	108.53	118.59	0.25002	1.3389	108.11	118.02	0.24363	1.0540	107.68	117.43	0.23847
100	1.8908	112.30	122.80	0.25767	1.3995	111.93	122.29	0.25140	1.1043	111.55	121.77	0.24637
120	1.9675	116.15	127.07	0.26517	1.4588	115.82	126.62	0.25900	1.1534	115.48	126.16	0.25406
140	2.0434	120.08	131.42	0.27254	1.5173	119.78	131.01	0.26644	1.2015	119.47	130.59	0.26159
160	2.1185	124.08	135.84	0.27979	1.5750	123.81	135.47	0.27375	1.2488	123.53	135.09	0.26896
180	2.1931	128.16	140.34	0.28693	1.6321	127.91	140.00	0.28095	1.2955	127.66	139.65	0.27621
200	2.2671	132.32	144.91	0.29398	1.6887	132.10	144.60	0.28803	1.3416	131.87	144.28	0.28333
220	2.3408	136.57	149.56	0.30092	1.7449	136.36	149.27	0.29501	1.3873	136.15	148.98	0.29036
240	2.4141	140.89	154.29	0.30778	1.8007	140.70	154.03	0.30190	1.4326	140.50	153.76	0.29728
260	2.4871	145.30	159.10	0.31456	1.8562	145.12	158.86	0.30871	1.4776	144.93	158.60	0.30411
280	2.5598	149.78	163.99	0.32126	1.9114	149.61	163.76	0.31543	1.5223	149.44	163.53	0.31086
	P = 60 psia (T_{sat} = 49.84°F)				P = 70 psia (T_{sat} = 58.30°F)				P = 80 psia (T_{sat} = 65.89°F)			
Sat.	0.7936	101.30	110.11	0.22127	0.6821	102.39	111.22	0.22080	0.59750	103.35	112.20	0.22040
60	0.8179	103.31	112.39	0.22570	0.6857	102.73	111.62	0.22155				
80	0.8636	107.23	116.82	0.23407	0.7271	106.76	116.18	0.23016	0.62430	106.26	115.51	0.22661
100	0.9072	111.16	121.24	0.24211	0.7662	110.76	120.68	0.23836	0.66009	110.34	120.11	0.23499
120	0.9495	115.14	125.68	0.24991	0.8037	114.78	125.19	0.24628	0.69415	114.42	124.69	0.24304
140	0.9908	119.16	130.16	0.25751	0.8401	118.85	129.73	0.25398	0.72698	118.52	129.29	0.25083
160	1.0312	123.25	134.70	0.26496	0.8756	122.97	134.31	0.26149	0.75888	122.68	133.91	0.25841
180	1.0709	127.41	139.30	0.27226	0.9105	127.15	138.94	0.26885	0.79003	126.89	138.58	0.26583
200	1.1101	131.63	143.96	0.27943	0.9447	131.40	143.63	0.27607	0.82059	131.16	143.31	0.27310
220	1.1489	135.93	148.69	0.28649	0.9785	135.71	148.39	0.28317	0.85065	135.49	148.09	0.28024
240	1.1872	140.30	153.48	0.29344	1.0118	140.10	153.21	0.29015	0.88030	139.90	152.93	0.28726
260	1.2252	144.75	158.35	0.30030	1.0449	144.56	158.10	0.29704	0.90961	144.37	157.84	0.29418
280	1.2629	149.27	163.29	0.30707	1.0776	149.10	163.06	0.30384	0.93861	148.92	162.82	0.30100
300	1.3004	153.87	168.31	0.31376	1.1101	153.71	168.09	0.31055	0.96737	153.54	167.86	0.30773
320	1.3377	158.54	173.39	0.32037	1.1424	158.39	173.19	0.31718	0.99590	158.24	172.98	0.31438

TABLE A–13E

Superheated refrigerant-134a (*Concluded*)

T °F	v ft³/lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R	v ft³/lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R	v ft³/lbm	u Btu/lbm	h Btu/lbm	s Btu/lbm · R
	P = 90 psia (T_{sat} = 72.78°F)				P = 100 psia (T_{sat} = 79.12°F)				P = 120 psia (T_{sat} = 90.49°F)			
Sat.	0.53113	104.21	113.06	0.22006	0.47760	104.99	113.83	0.21976	0.39644	106.35	115.16	0.21924
80	0.54388	105.74	114.80	0.22330	0.47906	105.18	114.05	0.22016				
100	0.57729	109.91	119.52	0.23189	0.51076	109.45	118.90	0.22900	0.41013	108.48	117.59	0.22362
120	0.60874	114.04	124.18	0.24008	0.54022	113.66	123.65	0.23733	0.43692	112.84	122.54	0.23232
140	0.63885	118.19	128.83	0.24797	0.56821	117.86	128.37	0.24534	0.46190	117.15	127.41	0.24058
160	0.66796	122.38	133.51	0.25563	0.59513	122.08	133.09	0.25309	0.48563	121.46	132.25	0.24851
180	0.69629	126.62	138.22	0.26311	0.62122	126.35	137.85	0.26063	0.50844	125.79	137.09	0.25619
200	0.72399	130.92	142.97	0.27043	0.64667	130.67	142.64	0.26801	0.53054	130.17	141.95	0.26368
220	0.75119	135.27	147.78	0.27762	0.67158	135.05	147.47	0.27523	0.55206	134.59	146.85	0.27100
240	0.77796	139.69	152.65	0.28468	0.69605	139.49	152.37	0.28233	0.57312	139.07	151.80	0.27817
260	0.80437	144.19	157.58	0.29162	0.72016	143.99	157.32	0.28931	0.59379	143.61	156.79	0.28521
280	0.83048	148.75	162.58	0.29847	0.74396	148.57	162.34	0.29618	0.61413	148.21	161.85	0.29214
300	0.85633	153.38	167.64	0.30522	0.76749	153.21	167.42	0.30296	0.63420	152.88	166.96	0.29896
320	0.88195	158.08	172.77	0.31189	0.79079	157.93	172.56	0.30964	0.65402	157.62	172.14	0.30569
	P = 140 psia (T_{sat} = 100.50°F)				P = 160 psia (T_{sat} = 109.50°F)				P = 180 psia (T_{sat} = 117.69°F)			
Sat.	0.33771	107.51	116.26	0.21879	0.29316	108.50	117.18	0.21836	0.25813	109.36	117.96	0.21795
120	0.36243	111.96	121.35	0.22773	0.30578	111.01	120.06	0.22337	0.26083	109.94	118.63	0.21910
140	0.38551	116.41	126.40	0.23628	0.32774	115.62	125.32	0.23230	0.28231	114.77	124.17	0.22850
160	0.40711	120.81	131.36	0.24443	0.34790	120.13	130.43	0.24069	0.30154	119.42	129.46	0.23718
180	0.42766	125.22	136.30	0.25227	0.36686	124.62	135.49	0.24871	0.31936	124.00	134.64	0.24540
200	0.44743	129.65	141.24	0.25988	0.38494	129.12	140.52	0.25645	0.33619	128.57	139.77	0.25330
220	0.46657	134.12	146.21	0.26730	0.40234	133.64	145.55	0.26397	0.35228	133.15	144.88	0.26094
240	0.48522	138.64	151.21	0.27455	0.41921	138.20	150.62	0.27131	0.36779	137.76	150.01	0.26837
260	0.50345	143.21	156.26	0.28166	0.43564	142.81	155.71	0.27849	0.38284	142.40	155.16	0.27562
280	0.52134	147.85	161.35	0.28864	0.45171	147.48	160.85	0.28554	0.39751	147.10	160.34	0.28273
300	0.53895	152.54	166.50	0.29551	0.46748	152.20	166.04	0.29246	0.41186	151.85	165.57	0.28970
320	0.55630	157.30	171.71	0.30228	0.48299	156.98	171.28	0.29927	0.42594	156.66	170.85	0.29656
340	0.57345	162.13	176.98	0.30896	0.49828	161.83	176.58	0.30598	0.43980	161.53	176.18	0.30331
360	0.59041	167.02	182.32	0.31555	0.51338	166.74	181.94	0.31260	0.45347	166.46	181.56	0.30996
	P = 200 psia (T_{sat} = 125.22°F)				P = 300 psia (T_{sat} = 156.09°F)				P = 400 psia (T_{sat} = 179.86°F)			
Sat.	0.22983	110.11	118.62	0.21753	0.14266	112.60	120.52	0.21512	0.09642	113.35	120.48	0.21161
140	0.24541	113.85	122.93	0.22481								
160	0.26412	118.66	128.44	0.23384	0.14656	113.82	121.95	0.21745				
180	0.28115	123.35	133.76	0.24229	0.16355	119.52	128.60	0.22802	0.09658	113.41	120.56	0.21173
200	0.29704	128.00	138.99	0.25035	0.17776	124.78	134.65	0.23733	0.11440	120.52	128.99	0.22471
220	0.31212	132.64	144.19	0.25812	0.19044	129.85	140.42	0.24594	0.12746	126.44	135.88	0.23500
240	0.32658	137.30	149.38	0.26565	0.20211	134.83	146.05	0.25410	0.13853	131.95	142.20	0.24418
260	0.34054	141.99	154.59	0.27298	0.21306	139.77	151.59	0.26192	0.14844	137.26	148.25	0.25270
280	0.35410	146.72	159.82	0.28015	0.22347	144.70	157.11	0.26947	0.15756	142.48	154.14	0.26077
300	0.36733	151.50	165.09	0.28718	0.23346	149.65	162.61	0.27681	0.16611	147.65	159.94	0.26851
320	0.38029	156.33	170.40	0.29408	0.24310	154.63	168.12	0.28398	0.17423	152.80	165.70	0.27599
340	0.39300	161.22	175.77	0.30087	0.25246	159.64	173.66	0.29098	0.18201	157.97	171.44	0.28326
360	0.40552	166.17	181.18	0.30756	0.26159	164.70	179.22	0.29786	0.18951	163.15	177.18	0.29035

APPENDIX C

GANTT CHART